2

Illustrated World of Science Encyclopedia

Biology I:
LIFE SYSTEMS
AND STRUCTURES

THE WORLD OF SCIENCE

THE HONEYBEE (*Apis mellifica*)

THE WORLD OF SCIENCE

VOLUME

2

BIOLOGY I

Life Systems and Structures

with

The Illustrated Science Dictionary

CREATIVE WORLD PUBLICATIONS, INC.
CHICAGO

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VOLUME 2

BIOLOGY I

Life Systems and Structures

INTRODUCTION

In Volume I, certain themes were woven through the articles on various aspects of biology; the themes appeared, disappeared, and reappeared with fascinating variations. Among these themes are: (1) the *diversity* of form and function that permits living matter to occupy so many ecological niches; (2) the basic structural and chemical *unity* of all forms of life on the Earth; and (3) the *recycling of elements* up and down the evolutionary scale of organisms.

The articles in the present volume are concerned with the first of these themes (the interaction of diversity and ecology) at four levels of organization: ecosystems, populations, individuals, and organ systems. At the ecosystems level, the kinds of flora and fauna in the desert, high mountains, arctic, and coral reef are introduced. The ingenious ways in which these diverse life-forms have evolved to survive and multiply in harsh environments are described, along with the considerable amount of cooperative interaction among the several species as well as between each species and the nonliving environment. The mechanisms of evolution and interaction are further developed in articles on Australian fauna, speciation, and symbiosis, parasitism, and commensalism.

At the population level, three groups of social insects are described: termites, ants, and honeybees. The first two have survived for at least 300 million years, and all three are highly organized with regard to assignment and performance of such functions as reproduction, food production, and protection from predators and environmental dangers. The kinds of individuals that develop are controlled by the colony itself, and each kind is well suited to its particular tasks. Each group performs amazing feats of biochemistry, engineering, and communication, and each has intricate and sophisticated interaction with the plant and microbial groups that share its environment.

At the level of individuals, this volume examines several types of response to the environment. One article describes the extensive migrations of birds, mammals, reptiles, and fish by means of such navigational aids as the stars and perhaps the Earth's magnetic field. Another article deals with the structural and physiological adaptations of bats that enable them to fly and feed in total darkness, and a third with the web-spinning ability of spiders. Other articles in this volume are concerned with the plumage of birds, the locomotion of aquatic animals, and the distinctive markings of male and female insects and animals.

The final articles deal with the cooperative interaction of tissue and organ systems—an interaction that results in functioning individuals. Roots, the organs of absorption and support for plants, are described. Additional articles deal with animal organs of protection and structural support (skin, skeleton, and connective tissue). Other organ systems described are concerned with locomotion (muscles and bones), digestion (teeth, the digestive tract, and the digestive glands), respiration, and excretion.

Additionally, two of the more complicated, extraordinary, and important groups of organs are described: the nervous and endocrine systems. The former article examines the structural features of sensory organs, of nerves and nerve tissue, and the nature of the nerve impulse. The marvelous mechanisms of sound transmission through the ear and light transmission through the eye are described. The articles dealing with the endocrine system describe six remarkable glands—the pituitary, adrenals, thyroid, parathyroid, pancreas, and gonads—glands with powerful abilities for control of the metabolism and well-being of the individual.

Thus, at each level of organization, the almost unbelievable amount of interaction and cooperation between the components of the particular system is presented; and the reader becomes aware that the individual is greater than the sum of its organs; that the population is greater than the sum of its individuals; and that the ecosystem is greater than the sum of its species.

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DESERT FLORA AND FAUNA

life in arid lands

Contrary to accepted fact, deserts are not always hot; indeed, they can be found in tropical, temperate, and arctic regions alike. Most, however, are located near the Tropic of Capricorn and the Tropic of Cancer (between latitudes 23° 30′ S. and 23° 30′ N.). Deserts may be sandy, pebbly, rocky, clayey, slaty, icy, or snowy; their most striking characteristic is the very scanty plant and animal life that exists there. Living things require water, and there is not much of it available in deserts, due to the lack of rainfall, to the inability of the earth to retain water, and because of the very rapid evaporation of water from the surface of the earth. Deserts usually have less than 250 mm (about 10 in.) of precipitation per year.

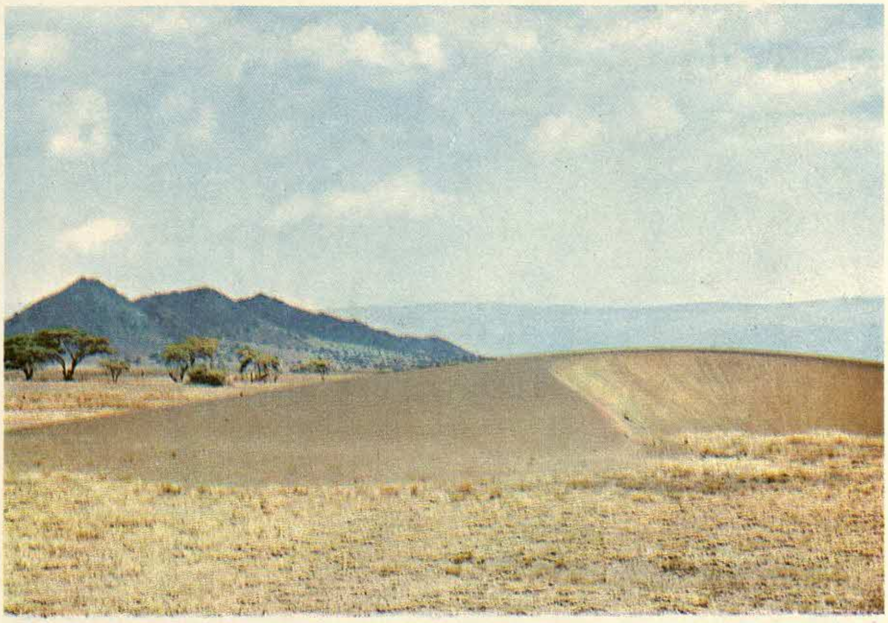
The study of survival in the desert has become an important one, for here the biologist finds forms of life adapted to living in these inhospitable regions that cover one-fifth of the earth's land surface. Deserts occupy 100 percent of the polar lands, 36.5 percent of Australia, 31.5 percent of North America, 29 percent of Asia, 20 percent of Europe, 18 percent of Africa, and 11 percent of South America, for a total of 29.78 million sq km (about 11.5 million sq mi).

PHYTOLOGIC ASPECTS OF DESERT LANDS

Desert plants are nearly all xerophytes—that is, plants that have adaptations enabling them to conserve water under arid conditions. Most desert plants are herbs or shrubs; trees are found only in oases where there are streams, pools, or subterranean water sources near the surface. Stems and leaves are covered by a thick cuticle, a waxy substance that is impermeable to water and that prevents water loss from the plants. The stomata (openings through which plants absorb the carbon dioxide they need) are sunk deep into the epidermis of some plants and may be covered by hairs that protect them from drying winds. The internal

DUNES—This is a typical aspect of the sandy desert (the Serengeti zone in Tanzania). The dunes are formed by the continuous action of wind on the sand. They take on varying forms, depending on whether the wind blows in only one direction (half-moon forms) or in different directions (stellar forms). This last type of dune is notably stable and can be of very large dimensions.

1



2

HALOPHILIC (SALT-LOVING) VEGETATION—In conditions that would seem to be unfavorable for any form of life whatsoever, some plant forms have developed. These are plants that are particularly adapted for life on the shores of Tuz Golu (in central Asia Minor), a saltwater lake that is now almost dry.

MONUMENT VALLEY IN ARIZONA—This is a rocky desert in which erosion by wind and water has created fantastic and imposing forms (Illustration 3).

3

4

5

6a

6b

TAMARISK—This typical desert plant is perfectly adapted to conditions of extreme aridity. It has supple branches that bear dense bunches of small leaves (Illustration 4).

ONE OF THE CACTACEAE—It looks like a huge flower and has tissues that store water. The thorny leaves also are useful as a defense against animals (Illustration 5).

CEREUS—This is the plant most typical of the American desert. Illustration 6a shows a much-branched cereus at Terra Fria (Mexico), while Illustration 6b shows a *Cereus giganteus* of the Colorado desert plateau. The latter has a columnar shape with less branching; the spiny surface is fluted, and the stalk can expand rapidly when the roots absorb water.

tissues may contain mucilaginous substances that hold water. Root systems are spreading or deep and absorb as much water as possible.

Some species of tamarisk are covered with a saline secretion of calcium chloride and magnesium chloride, both of which are extremely hygroscopic and absorb the small amount of water vapor that forms near the ground at night; the water then passes through the plant's epidermis and stomata. The grasses, which absorb water from the soil, have much-branched roots with abundant root hairs that double or treble their water absorption capacity. An adaptation of cacti and some other desert plants is the modification of leaves into thorns, with the stem serving as both the photosynthetic and the water-storing organ.

ZOOLOGICAL ASPECTS OF DESERT ZONES

Because animals are dependent on plants, the animal life of the desert is naturally scarcer than it is elsewhere. The animals vary according to the type of desert and the continent. Mammals of the desert include the dorcas gazelle and the antelope in the hot, sunny plain, and the Barbary sheep in the mountains, where adequate grazing land and greater quantities of water can be found. Almost extinct and typical of the blazing desert lands of part of the Sahara and of the Arabian desert are the gazelles of the Arabian desert (the desert that covers about 86,000 sq mi of Egypt's land) and the white gazelle (*Oryx laucoryx*). With the exception of these few animals, the mammal population of the desert is made up of individuals that typically are small and have light-colored coats that permit them to hide easily in their surroundings. Among these, the rodents are the most numerous; the carnivores are also represented by a few species, most notably the desert fox.

A characteristic common to many species of animals living in these water-scarce areas is that of producing water endogenously—that is, as a by-product of the process of oxidizing food. For ex-

GAZELLE—One of several animal species found in herds in the desert zones of Africa and southeastern Asia is the gazelle. Its body is agile and elegant; its coat is darker on the back and almost white on the neck and belly.

7

8

BARBARY SHEEP—This animal, *Ammotragus lervia*, usually lives in the mountainous zones of the desolate Sahara Desert, sometimes climbing to as high as 2,000 m (about 6,600 ft). It adapts itself quite easily to life in captivity.

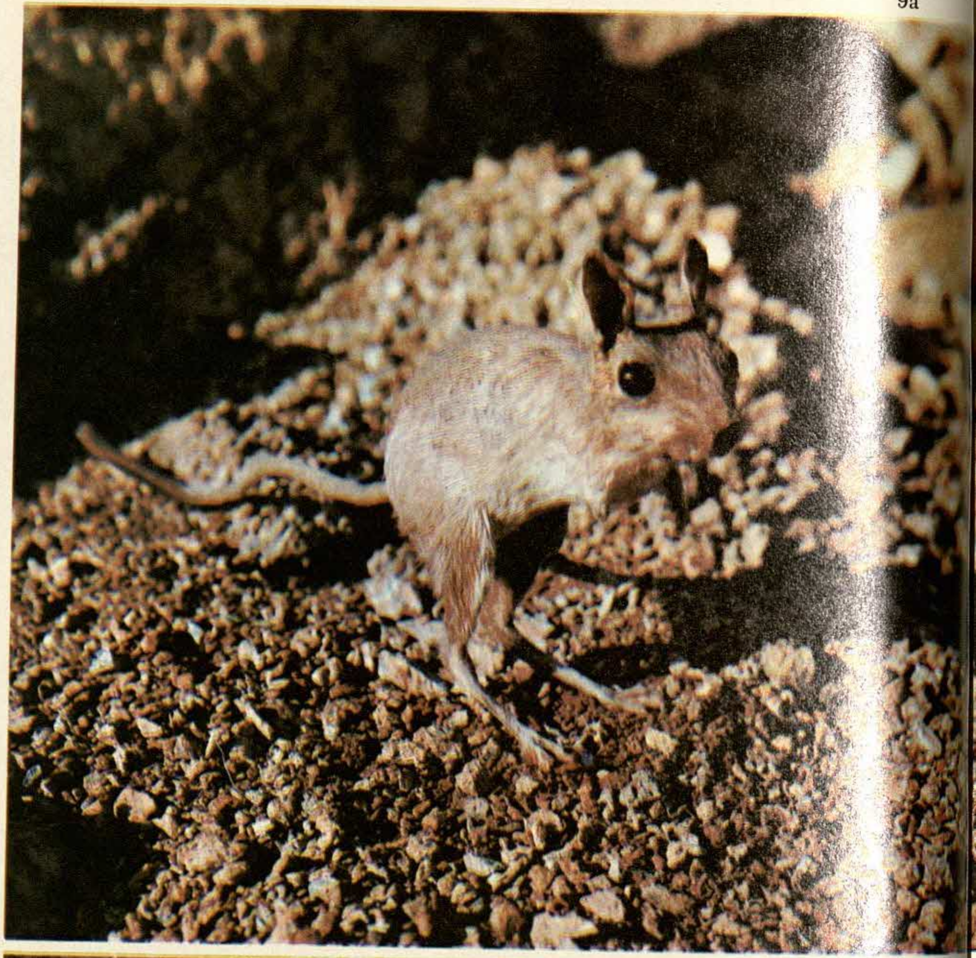
ample, desert animals can obtain 107.1 gm (about 3.8 oz) of water by oxidizing 100 gm (about 3.5 oz) of fat, 50 gm (about 1.8 oz) from 100 gm (about 3.5 oz) of carbohydrates, and 41.3 gm (about 1.5 oz) from 100 gm (about 3.5 oz) of proteins. This water, together with the small amount that is present in their food, is sufficient for their needs. The carnivorous animals obtain water directly from the blood and meat of their prey.

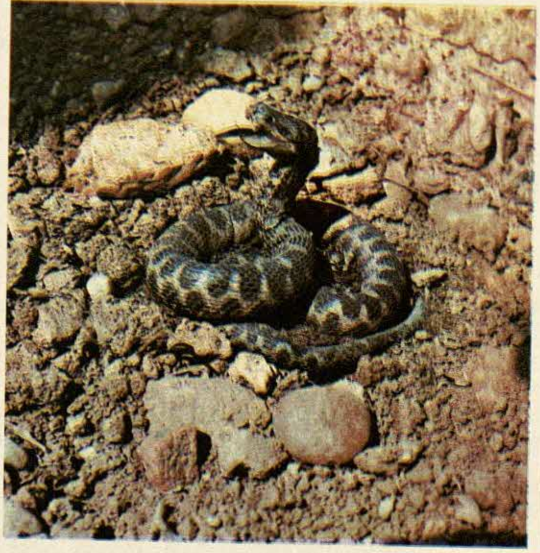
Another important factor in the survival of many desert animals is their nocturnal habits. At night the humidity is higher and the temperature is lower than during the day, and these factors cause a decrease in perspiration at night. During the day, when the sun scorches the bare earth, animals go underground, remain in the shade of rocks, or stay close by any existing vegetation.

Many species of desert mammals have unusually long hind limbs that are very strong and are suited to jumping. The forelimbs are smaller. This is most common among the rodents (such as jumping rats and mice), which move about by making broad jumps that are disproportionately long for their size. Their jumps enable them to cover great distances in the search for food—plants, insects, or scraps from the meals of larger animals. Desert birds can also move rapidly from place to place when seeking the most suitable spot. But generally, those species that dwell permanently in the desert remain close to the oases—the only places where they can find a suitable environment and a steady diet of insects, reptiles, and small mammals.

The most abundant vertebrates—and the most interesting because of their particular adaptations to the unfavorable desert climate—are the snakes and lizards. These reptiles are poikilotherms, or animals that cannot regulate their body temperature, which varies with that of the environment. They are so sensitive to heat that temperatures of more than 39° C (102.2° F) are soon fatal to them. In the summer, the temperature in the

9a





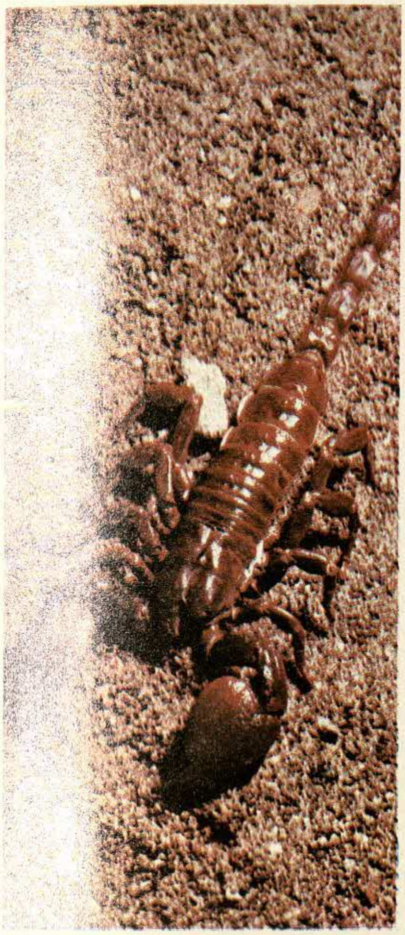
9b

DESERT ANIMALS—Illustration 9a shows a typical desert rodent, *Laculus orientalis*. This rodent is an extremely able jumper with highly developed hind legs; like most desert animals, it has nocturnal habits.

The snake, *Vipera aspis* (shown in Illustration 9b), is very common in Italy in dry, rocky zones. These reptiles have skin covered with scales that prevent perspiration, thus making them well suited to life in arid environments.

During the day tarantulas (like those shown in Illustration 9c) live in silk-lined tunnels dug 15 to 20 cm (about 6 to 8 in.) deep in the ground; they leave their refuges only at night.

9d



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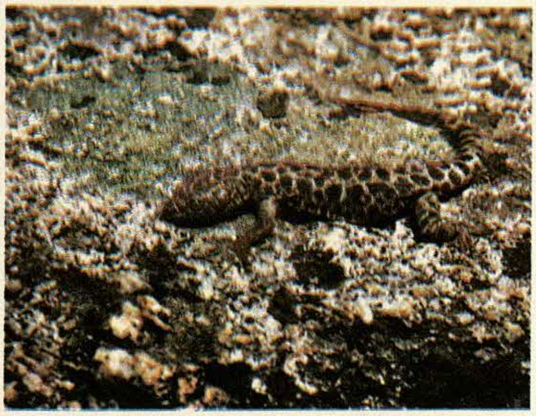

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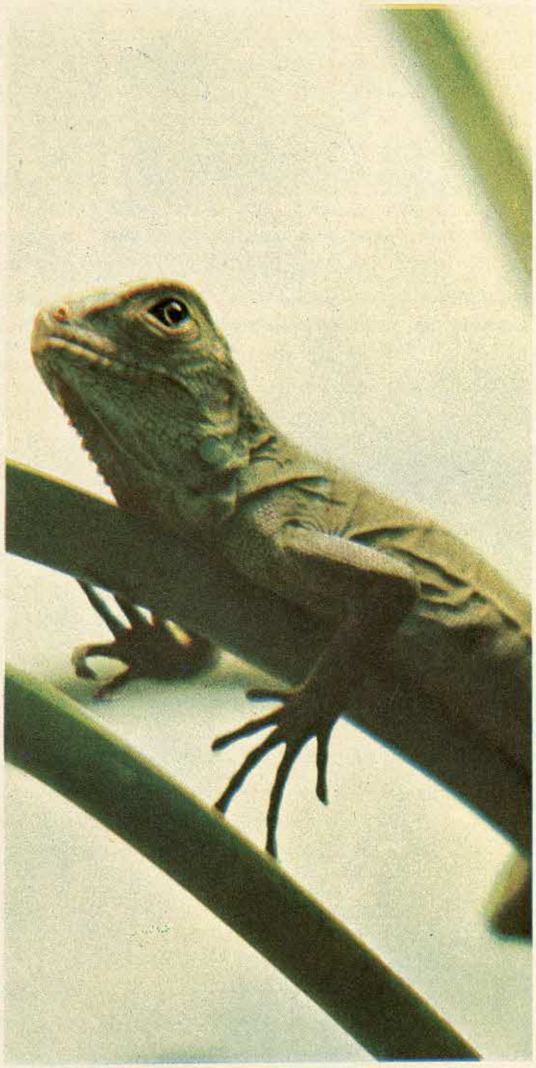


9f

Illustration 9d shows one of the scorpions, *Padinus imperator,* which measure as much as 18 cm (about 7 in.) in length. This species is one of the principal victims of the sand viper.

Of the creatures living in the desert, the lizards appear to be the most numerous during the day, even at the hottest times, because of their marked ability to regulate body heat. A specimen of *Xantusia vigilis* is seen in Illustration 9e. The iguana (Illustration 9f), an interesting bright green reptile, lives in burrows in the earth and is vegetarian.

desert reaches 65-70° C (149-158° F) in the sun and more than 40° C (104° F) in the shade. At temperatures of less than 15° C (59° F), desert snakes become sluggish and are easy prey. Their system of heat regulation consists in hiding themselves under a layer of sand, at a depth more or less in accord with the outside temperature. Only their eyes, which are covered by horny protuberances, remain exposed. In this position they await their prey, capturing it with lightning speed, and then, with their victim in their jaws, quickly returning to their hiding place or lair. Here they lie with their bodies touching the walls, giving off the excess heat accumulated during their brief exposure to the sun. Once their normal temperature is re-established, they swallow their prey and return to the surface to hide under the sand once more.

In addition to the vertebrates, the desert contains a notable number of invertebrates, almost all of which are insects or arachnids. These, too, have predominantly nocturnal habits and are endowed with the ability to recover water endogenously. The arachnids, for the most part, are scorpions, vinegaroons, and spiders, while nearly all the insects are beetles. Their ability to adapt themselves to the most diverse climatic conditions is almost unlimited; there are some species, such as the desert mantis, that can tolerate temperatures as high as 51° C (123.8° F).

At the oases other animals, both vertebrate and invertebrate, depend for their survival on an abundant supply of water. Their present distribution in isolated oases in the desert indicates that at one time there must also have existed an extensive water system and different climatic conditions. These animals are reptiles (such as the crocodile), amphibians (toads and frogs), fishes, and insects. Today, the creatures are limited to a small number—all destined to die out because of the desiccation of the water in the deserts of the world.

PLANTS AND ANIMALS OF HIGH MOUNTAIN REGIONS

life at high altitudes

The plants and animals on any mountain differ with altitude because environmental conditions change with altitude, and only those species adapted to the conditions of a given area or zone can survive there. Temperature, sunshine, humidity, rainfall, wind, the type of rock or soil—all are environmental factors that determine the kinds of plants and animals that live in a given zone. Several more or less distinct life zones can be found on the slopes of most mountains.

VEGETATION ZONES

Temperature is one of the most important of the environmental factors that delimit life zones, the climate usually becoming colder with increasing altitude. The tops of very tall mountains are in perpetual winter, their rocky surfaces always covered by snow and ice.

Below the mountaintops, in a zone of somewhat warmer temperatures, the snow melts during part of the year, and there is a short growing season. This zone is called tundra; it resembles the Arctic tundra of northern Eurasia and North America, but because it is located on mountains, it is called alpine tundra. In the uppermost part of this zone, there may be no plants at all, or only lichens growing on bare rock surfaces. In the lower part of the alpine tundra grow mosses, grasses, other herbs, as well as small shrubs; but this zone cannot support trees.

Lichens are not single plants, but symbiotic associations between fungi and algae. The fungus is the larger plant, and growing within it are unicellular algae. Lichens are resistant to extremes of heat and cold and to long periods of drought. As such, they are well suited to life on the exposed rocks of high mountains. By day, direct sunshine can raise the rock temperatures high enough to kill many other kinds of plants, while at night the temperatures may fall to below freezing. Between rains, the rock is usually dry. Few other plants can survive such a combination of extremes.

Because of their hardy nature, lichens are pioneer plants; they are the first to colonize new areas, not only in high altitudes but in lower ones as well. Lichens produce chemical substances that react with rock and cause some disintegration of it. This, coupled with physical weathering by wind and water, breaks the rock down into small particles. The addition of the decaying bodies of dead lichens creates an extremely thin layer of soil on which mosses, grasses, and other small plants can grow. The deaths of these plants build more soil on which even larger plants can grow. Today, when most glaciers are melting and their fronts are retreating slowly up mountainsides, lichens are the first plants to follow them upward.

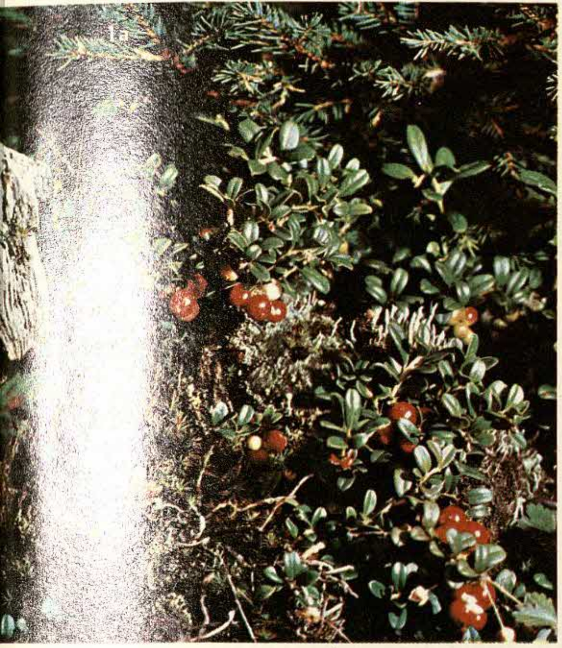
At timberline, stunted trees grow; below the timberline grow trees of normal height. The trees near timberline are usually coniferous, the exact species varying with altitude, exposure of the slope, and the geographical location. One study of a mountain in Arizona revealed four distinct bands of coniferous trees within the zone; beginning with the uppermost, they were: spruce, Douglas fir, ponderosa pine, and piñon pine. Most conifers are evergreen, and their leaves are needle-shaped rather than flat like those of most deciduous trees. The needle, being more compact than a flat leaf, presents less surface to the air. These properties of coniferous leaves reduce the amount of water that can be lost by transpiration in the cold winter air, the drying effect of which is enhanced by the winds that so often blow unhindered at high altitudes. Only a few species of conifers adapt to winter by losing all their leaves; larch and bald cypress are deciduous.

Below the zone of coniferous trees, the climate is warmer and the vegetation varies with geographical and climatic conditions. Deciduous trees, desert, or grassland may occupy this zone, and it, too, may be divided into several distinct regions. Annual rainfall may vary from less than 10 in. in the desert to 30 in. in the temperate deciduous forest. Both have well-defined seasonal changes.

The vegetation zones on a given mountain are usually not perfectly horizontal but have an obvious slope. Because the slope facing the sun (the south-facing slope in the northern hemisphere and the north-facing slope in the southern hemisphere) receives more sunlight than the opposite slope, a given altitude on the sunny slope is likely to have somewhat warmer temperatures than the same altitude on the shady slope. For this reason, vegetation bands on mountains of the northern hemisphere tend to slant downward from a higher point on the south-facing slope to a lower point on the north-facing slope. The slant is in the opposite direction on mountains of the southern hemisphere.

The pattern of the zones is also modified by the direction of the prevailing winds and whether they are dry or laden with moisture. Local variations in the shape of the mountain cause additional modification; the steepness of the slope, for example, determines how much water is retained or how fast it drains off.

Because a given zone occupies a different height at different latitudes, the number of vegetation zones on any given mountain depends on the height of the mountain and its location. At the equator, the alpine tundra occupies the tops of only the tallest mountains, but the same kind of tundra can be found at moderate altitudes in the temperate zone and near sea level in the polar regions. Thus, a very tall mountain on the equator may have many vegetation zones; but a small mountain has only those zones characteristic of low altitudes in the tropics. Near the poles, mountains of any size may have only one vegetation zone—the tundra—or if conditions are extreme enough, the mountains may be covered perpetually by glaciers.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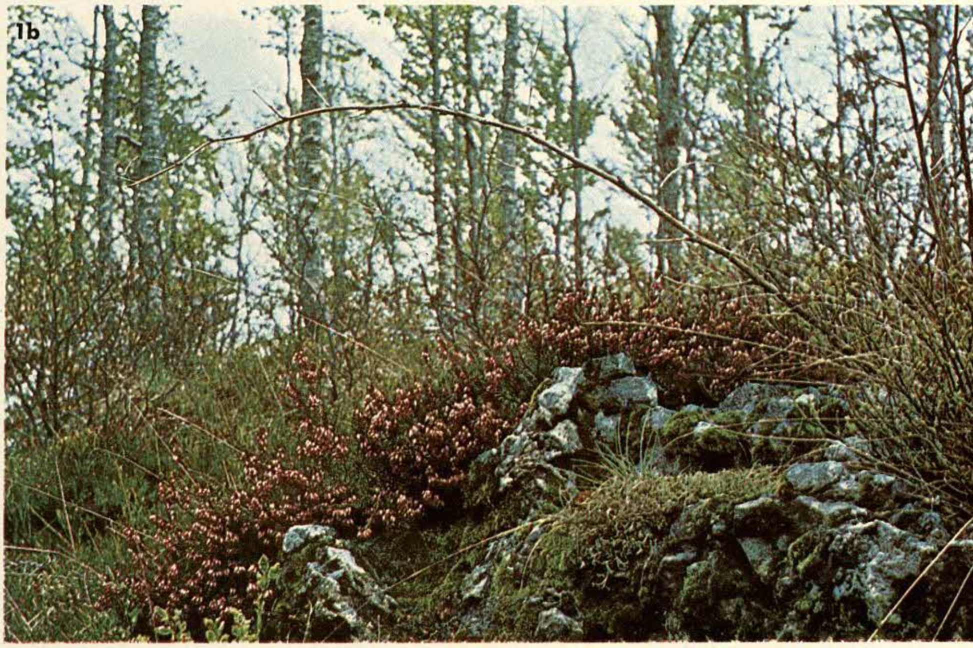
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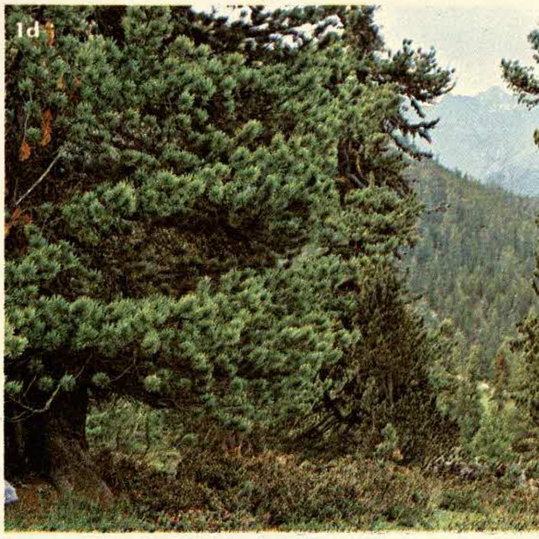
A VARIED AND TYPICAL FLORA—The plants of mountain heights include trees, shrubs, herbs, algae, fungi, and lichens. A snow cover protects small trees and shrubs from the cold, drying winds of winter; some of these plants retain their leaves throughout the year. A given factor such as temperature or moisture does not always act in absolute fashion; a plant's reaction to it may vary with other conditions. The photographs show some of the most common examples of mountain flora: **(1a)** a colorful tuft of *Vaccinium myrtillis* (whortleberry); **(1b)** *Erica carnea* (spring heath); **(1c)** two specimens of *Pinus cembra* (Swiss stone pine) among larches; **(1d)** a detail of the foliage of the same tree; **(1e)** some typical low shrubs of *Pinus mugo* (Swiss mountain pine) growing over rocks.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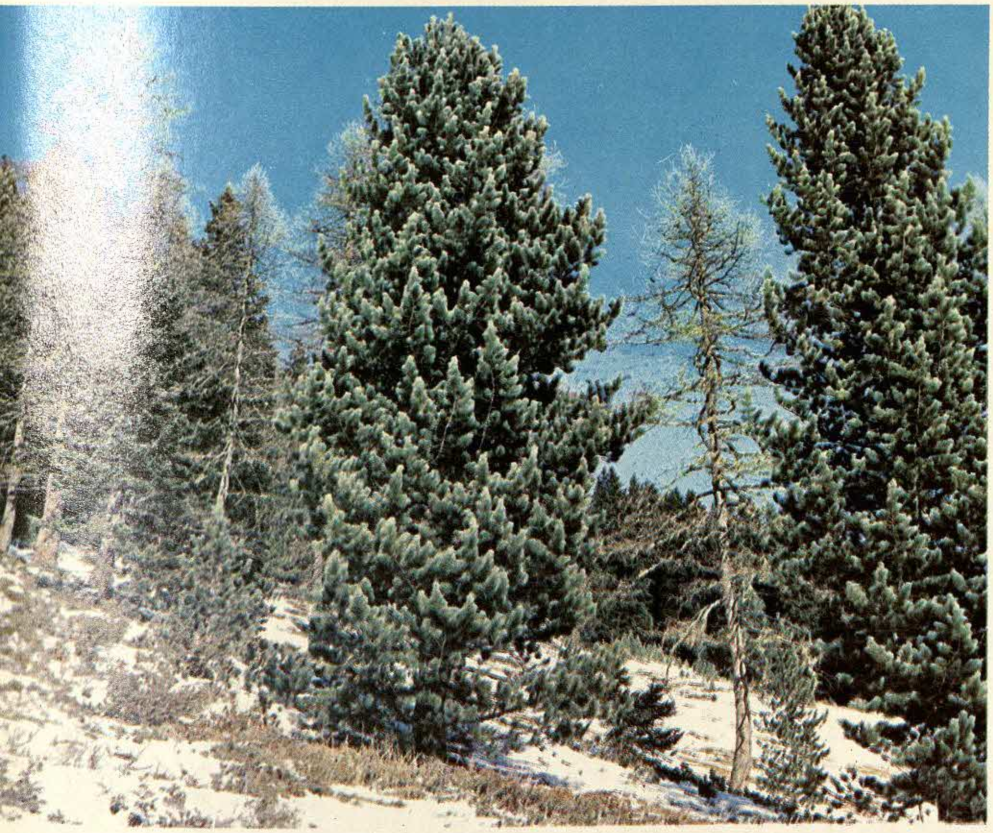
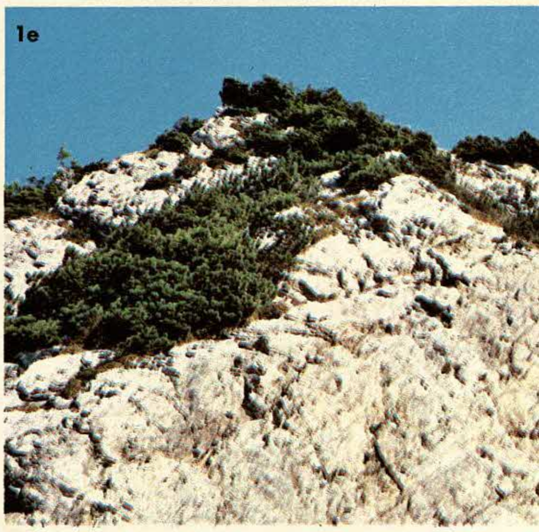



1e

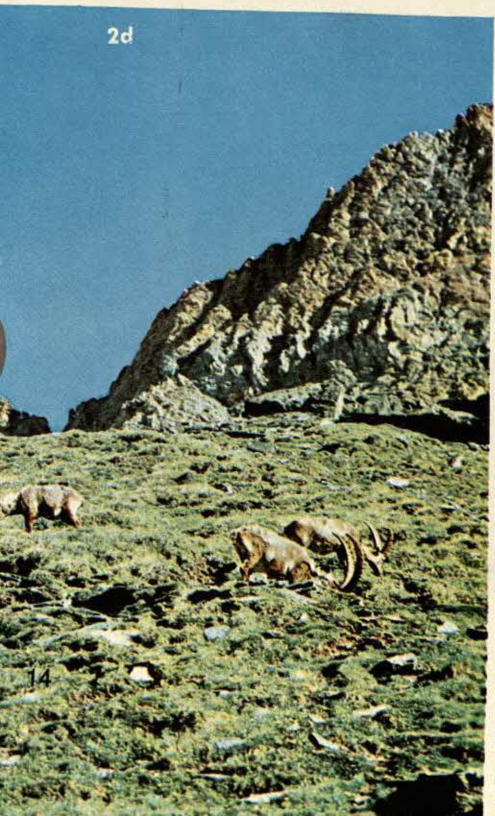
2a

2b

2c

PLANTS AND ANIMALS OF THE MOUNTAIN HEIGHTS—Along with the higher plants, some lower forms of life—algae, fungi, and lichens—thrive in the mountains. Trees are not found above the timberline, but small shrubs and herbs grow at higher altitudes, as do algae, fungi, and lichens. On the highest outcroppings of rock only lichens can be found. These plants are actually symbiotic associations between fungi and the algae that live within them. Some species of lichen can survive on bare rock, and many of them are pioneer plants at high altitudes and in other barren places. Mountain fauna are represented by a large number of species; some are typical only of the heights, while others are common everywhere. The pika (*Ochotona wollastoni*) lives at about 20,000 ft on Mt. Everest. Forest faunas ascend to the vegetational limit; then a characteristic alpine fauna appears. In the photographs: **(2a)** some small plants of *Vaccinium vitis* in fruit; **(2b)** a lichen, *Evernia furfuracea*, on a branch of a conifer; **(2c)** another group of lichens on *Abies alba* (silver fir); **(2d and 2e)** typical examples of mountain fauna, the ibex (*Capra ibex*); **(2f)** a specimen of the capercaillie or tree grouse (*Tetrao urogallus*), a bird with a diet of pine needles.

2f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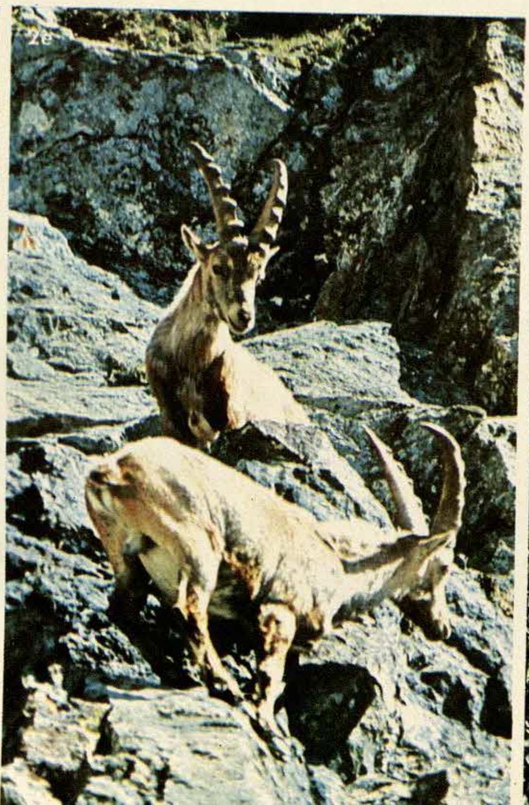
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ANIMALS OF THE MOUNTAINS

Because animals are dependent on plants for their food and often for their shelter, the vegetation of a given area naturally determines what animals live there. The capercaillie, for example, is a tree grouse with a most unusual diet; it is one of the few animals that eat pine needles, and so the capercaillie is usually found in pine forests. The altitude at which an animal lives varies with that of the vegetation zone it prefers. In the Andes mountain system of South America lives a bird called the seed snipe; it is related to the plovers, but unlike its relatives, it feeds on alpine tundra vegetation. In Ecuador, near the equator—where the alpine tundra is at its highest altitude—the seed snipe is found at 4,300 m (about 14,000 ft). At the southern tip of South America, in frigid Tierra del Fuego, these birds live and feed at sea level.

Many large animals of the mountains migrate up and down the slopes as the seasons change. In the summer, for example, deer, elk, and wild sheep feed on the high pastures. In the winter, when this forage is covered by deep snow, these animals move to lower altitudes where food is more easily obtained and where they can find shelter from the winds. In the spring, the animals return to the higher altitudes. Caribou, however, sometimes occupy high slopes in the winter, if the winds are strong enough to keep their feeding grounds free of snow. Not only do herbivorous animals migrate with the seasons; the canivores that feed on them must follow them, too. Mountain lions, wolves, foxes, and weasels follow their prey.

A few animals adapt to the cold of winter by hibernating in caves or under the snow. Because of their size, bears are perhaps the most conspicuous hibernators, but woodchucks and other small mammals hibernate, too.

ISOLATION ON MOUNTAIN TOPS

The conditions in a given life zone—the tundra, for example—are similar throughout the world, whether the tundra is the Arctic tundra of Siberia or Canada or the alpine tundra of the Alps or the Andes. Similar types of vegetation and animals are found under similar conditions because the plants and animals must adapt to the same kinds of environment. The inhabitants of the Arctic tundra tend to be somewhat more uniform, for the Arctic tundra consists mainly of two large areas covering thousands of square miles. Populations living in the Alaskan and Canadian tundras are free to interbreed with each other; this keeps the populations relatively uniform, although some differences always exist among the organisms.

Alpine tundra, on the other hand, is discontinuous, and might be compared with islands rising above the sea. Tundra animals living on one mountaintop may never see or mate with animals living on the tundra of an adjacent mountaintop, for to do so would require traveling through inhospitable life zones below. Birds and very large mammals may find it convenient to make such trips, but medium-sized and smaller mammals as well as many insects and other small invertebrates are confined to their own mountaintops. A situation like this leads to inbreeding and the development of subspecies peculiar to a mountaintop, a mountain valley, or perhaps an entire mountain range.

Some mountaintops harbor the last members of species that were once widespread in earlier geological times. These animals are called relic species. About 10,000 years ago, the last great period of glaciation of Europe and North America drew to an end. During this period, plants and animals that had adapted to tundra-like conditions lived near the edges of the glaciers. As the climates became warmer and the glaciers melted, these plants and animals followed the retreat of the continental glaciers northward and the alpine glaciers upward on the mountain slopes. In the lower valleys, flora and fauna typical of warmer climates appeared, but some relic species survived on the upper slopes of such higher mountains as the Alps.

The life on mountaintops today includes the few relic species that remain and the more recent species that have entered this domain. Together they form a variety of interesting communities.

ARCTIC FLORA AND FAUNA | life near the North Pole

References to the Arctic Circle often evoke thoughts of lands permanently covered by snow or glaciers and of icebergs floating in frigid waters. Part of the region north of the Arctic Circle is indeed like this. Most of Greenland lies under glacial ice, and the sea around the North Pole is covered by an ice pack. But in the southern part of the Arctic area, a region known as the tundra, the Earth is released from the grip of winter for two or three months of the year.

The tundra occupies the northernmost areas of North America, Lapland, and Asia. Its southernmost limit coincides approximately with 60° north latitude, but because its extent is determined by climatic conditions, the boundary does not follow one particular line of latitude. In North America the tundra occupies much of Alaska and the northernmost part of western Canada, but in the east it dips farther south and encompasses the Hudson Bay area. Alpine tundra, which resembles Arctic tundra in many ways, occurs on high mountaintops in temperate and even tropical areas.

1

The regions occupied by Arctic tundra today were under one or more of the continental glaciers that spread over much of the Northern Hemisphere during the Pleistocene period. Many of these vast northern regions are relatively flat as a result of the leveling action of the heavy glaciers that ground rocks into fine particles and carried them southward as they advanced.

This is a land of temperature extremes. On summer days temperatures may reach 21°C (69.8°F) or higher. In the winter they can plunge to −63°C (−81.4°F). Life in the winter is made difficult not only by the cold weather but by the lack of light. Nights are long, and in the middle of the winter the sun does not rise above the horizon.

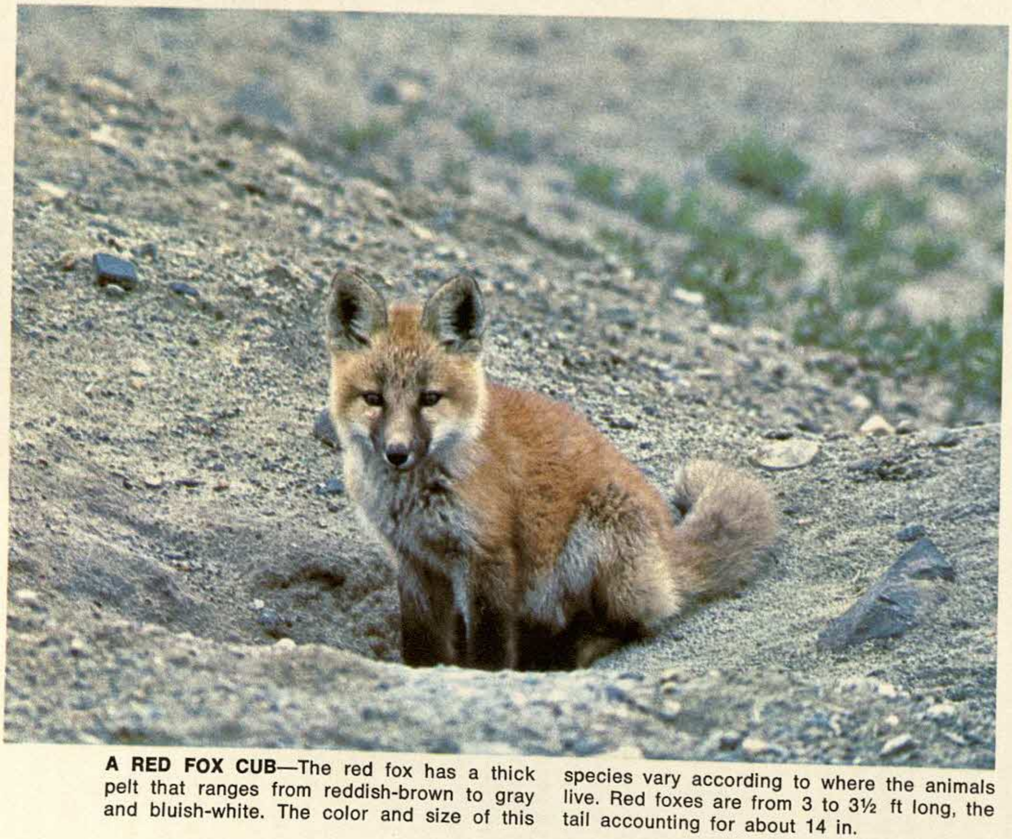
The summers are short, but the summer days are long. In the middle of summer the sun does not set, and there is light 24 hours a day. In the northern part of the tundra, light is continuous for several months. Throughout these many hours of sunlight, plants can synthesize food, and animals can bring food to their young. The vegetation bursts into bloom and produces seed before the long winter sets in again. Most Arctic animals give birth or lay eggs early in summer, and then they must raise their young to a stage where they are ready to migrate towards fall. No reptiles live in the Arctic, and most birds are migrants.

PERMAFROST

One of the characteristics of tundra is the presence of permafrost in the ground. Underlying the upper soil is permanently frozen ground that never thaws, even in the long summer days. The thickness of the permafrost layer is variable. At the southern limit of the tundra it may be so thin as to be almost nonexistent. To the north it may exceed 300 m (about 1,000 ft) in thickness. Its temperature varies from 0°C (32°F) to below −5°C (23°F).

Permafrost is impermeable to water and does not permit much drainage. When the upper soil layers thaw, each slight depression in the surface becomes a pool of water. Pools and lakes are characteristic of tundra and cover half its surface. Even the land areas can be spongy and swampy in the summer. Often it is more difficult to walk across the tundra in summer than in winter when the frozen ground is firm.

Contraction of the subterranean permafrost in the winter produces a polygonal pattern of cracks through which water enters during the spring thaw. The water freezes and fills the cracks with ice. When the permafrost expands in the summer, it is forced to expand upward because of the filling of the cracks. This process is repeated every year. The polygons may have a diameter of 15 m (about 50 ft) though many are smaller; and they often have heights of 20 to 30 cm (about 8 to 12 in.). Sometimes conical mounds known as pingos are produced, which occasionally may be as much as 100 m (about 330 ft) high.



A RED FOX CUB—The red fox has a thick pelt that ranges from reddish-brown to gray and bluish-white. The color and size of this species vary according to where the animals live. Red foxes are from 3 to 3½ ft long, the tail accounting for about 14 in.

2a

TAIGA—The southern limit of the tundra is bounded by coniferous forest known as taiga. Illustration 2a shows taiga of the Alaskan interior, in the foggy valley of the Nenana River. Illustration 2b shows the tundra in bloom in summer.

ARCTIC PLANTS

Plants of the tundra include lichens, mosses, grasses, sedges, willows, alders, birches, poplars, cranberries, bearberries, and crowberries. In the northern area or at high altitudes where the temperature is coldest and the ground is dry, all the plants are dwarfed. Willow trees may be less than 5 cm (about 2 in.) high. Lichens are numerous, and many of them provide bright splashes of color on the rocks they encrust. One lichen, *Cladonia*, is known as reindeer moss because it is the main food of reindeer and caribou, which browse on a wide variety of other plants as well.

In the southern part of the tundra and at low altitudes the climate is not quite so cold and the ground is wet throughout the summer. Here the plants are somewhat larger, and the tree species have a shrubby aspect and may be about 1 m (about 3 ft) tall.

In season wild flowers are abundant, and they bloom in profusion. One of their adaptations to the Arctic environment is their flowering response to day length. They bloom only during long days, thus avoiding the danger of late winter frosts. Other Arctic plants rely on vegetative reproduction. They produce new shoots from underground stems or roots.

ARCTIC ANIMALS

Mammals typical of the tundra include the caribou and reindeer (a domesticated form of caribou), musk-oxen, polar bears, Arctic foxes, and Arctic hares. Birds of the Arctic include snowy owls, ptarmigan, Arctic terns, plovers, phalaropes, snow buntings, Canada geese, whistling swans, snow geese, razorbills, and several species of gulls.

Red foxes, timber wolves, and brown and grizzly bears are common in the Arctic, but their ranges extend widely through the Temperate Zone as well.

2b

Some of the tundra animals such as caribou, reindeer, and musk-oxen are large animals living in herds. They require a great deal of vegetation for a single day's food supply, and because the vegetation is sparse the herds wander over great distances in search of food. Herding is also a defense mechanism, the stronger animals protecting the weaker

TUNDRA VEGETATION—Toward the end of May, when the snow begins to melt, the tundra becomes covered with vegetation. The saxifrages (Illustration 3a), which are especially abundant, are found among the pools and small lakes typical of this region. Illustration 3b shows the bright spots of color made by lichens on rocks. An encrustation of *Caloplaca elegans* on a rock is shown in Illustration 3c. The bright red fruiting bodies of a cluster of *Cladonia* are seen in Illustration 3d.

RANGES OF ARCTIC ANIMALS—These maps indicate the distribution (in orange) of some of the most common inhabitants of the polar regions. Most numerous are the collared lemming (*Dicrostonix hudsonius*), whose range is shown in Illustration 4a; the Arctic fox (*Alopex lagopus*), Illustration 4b; and the snowy owl (*Nyctea scandiaca*), Illustration 4c. The ranges of other animals typical of these regions are shown in the other maps. Illustration 4d shows the range of the snow goose (*Chen hyperborea*), which nests in large colonies; Illustration 4e, the musk-ox (*Ovibos moschatus*); and Illustration 4f, the razorbill (*Plotus alle*).

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ones. This instinct is particularly well developed in the musk-oxen, which form an impenetrable defensive ring around their young ones when danger threatens.

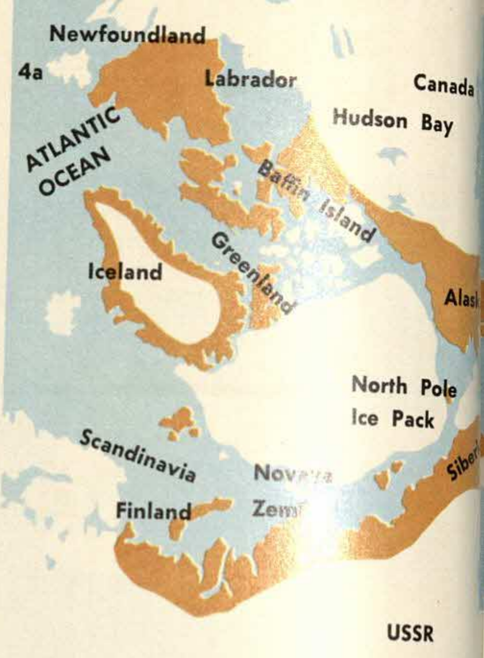
Only a few animals are year-round residents of the Arctic. These require adaptations to survive the severe winters. The polar bear grows a thick layer of subcutaneous fat and thick fur that act as insulation against the cold; the fur on the soles of its feet gives good traction on ice. The musk-ox has an inner coat of dense fur that provides excellent insulation and an outer coat of long coarse hairs that repel rain and snow. In winter several animals have white fur or feathers that make them less easily seen against the snow; the Arctic hare, the Arctic fox, and the ptarmigan change their white color for brownish hues in the summer.

Many of the tundra animals are large, especially those that remain during the winter. The large size gives a relatively small amount of surface area as compared with the volume of the body. Because heat is lost to the environment through the body surface, a small surface area is a heat-conserving adaptation.

Other tundra animals migrate south and avoid the rigors of the winter. Caribou migrate to the coniferous forests south of the tundra. Most birds fly south to temperate or tropical climates. The Arctic tern, which migrates farther than any other animal, enjoys two summers every year—one in the Arctic and the other in the South Temperate Zone.

Some animals hibernate during the winter. These include the brown and grizzly bears and some small mammals such as the ground squirrel and the collared lemming. In the summer, the tundra is notorious for its swarms of flies and other insects. The adults usually die when the Arctic winter arrives, but the eggs or larvae remain dormant and survive until spring.

4a



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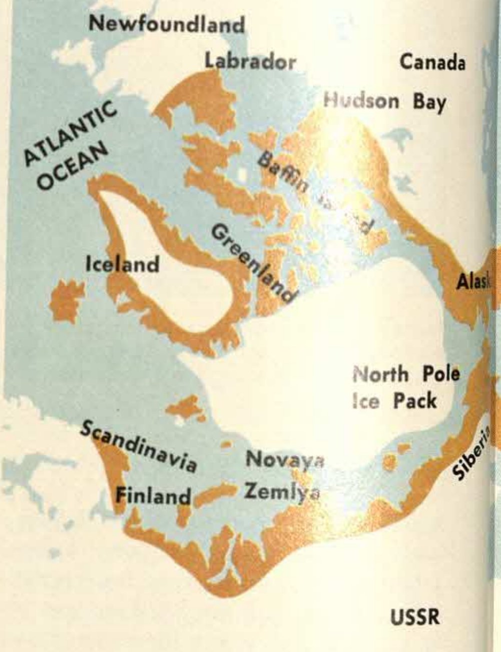

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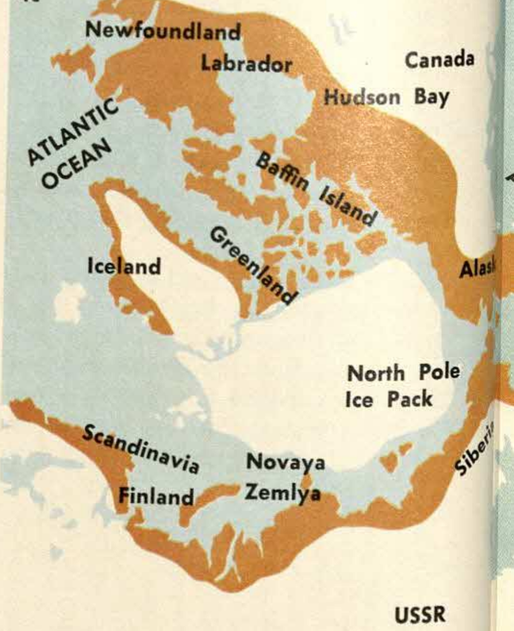

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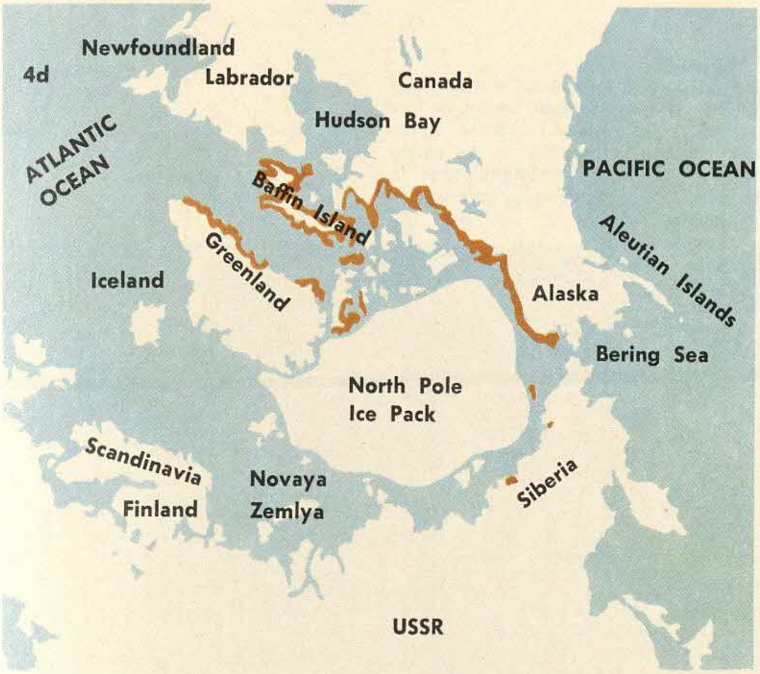

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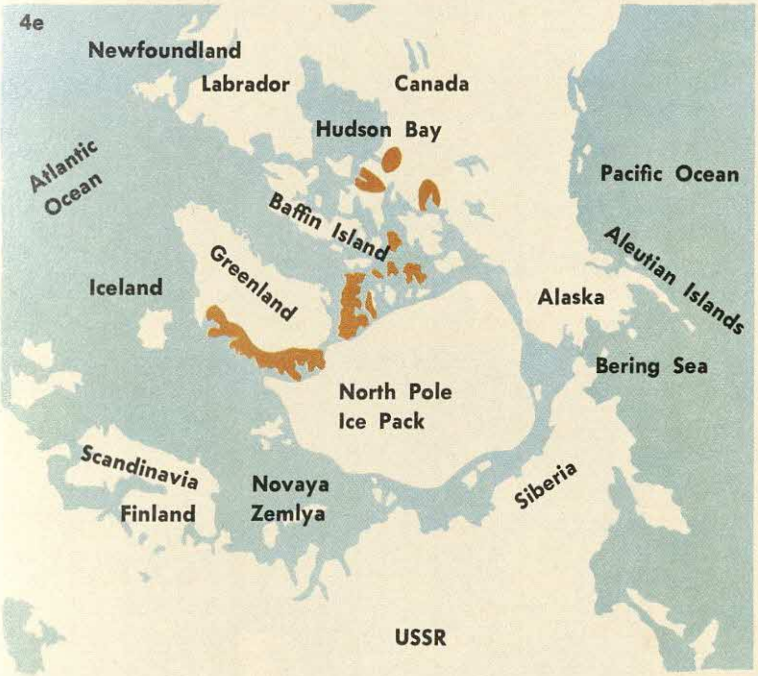

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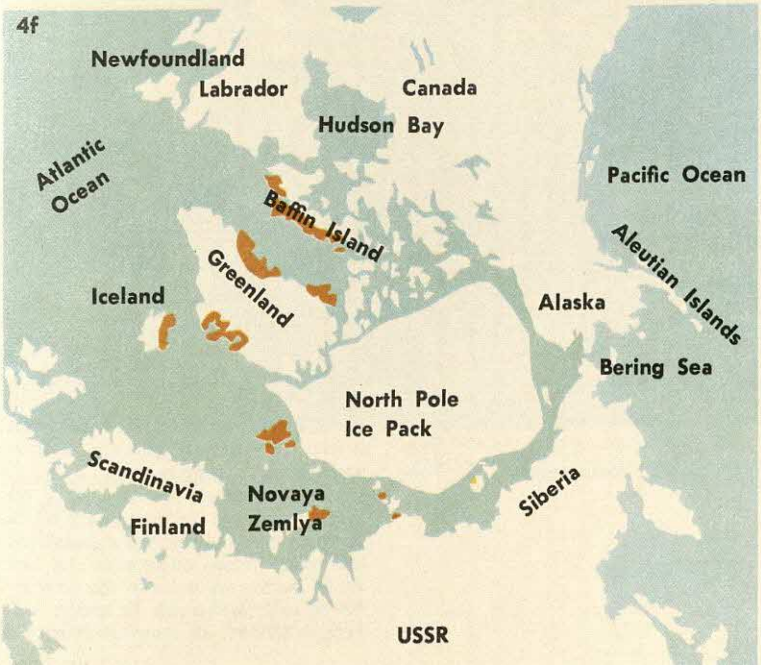
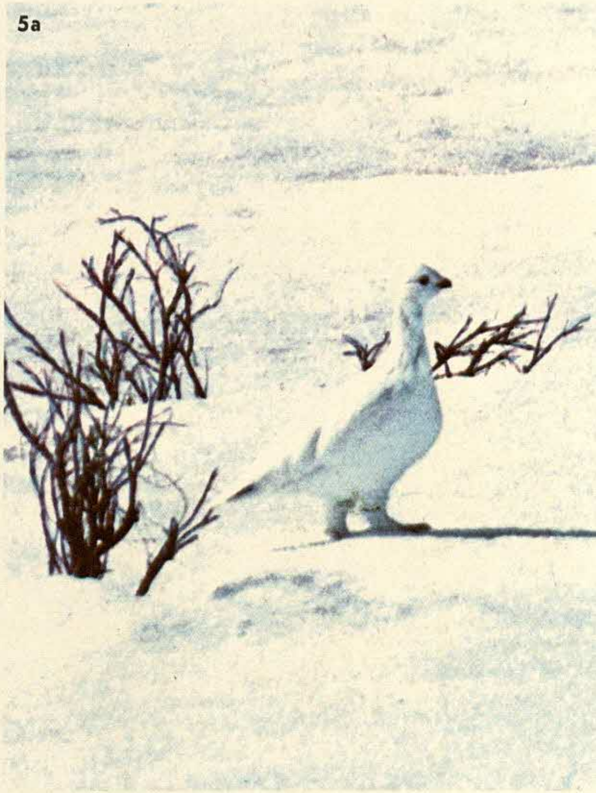
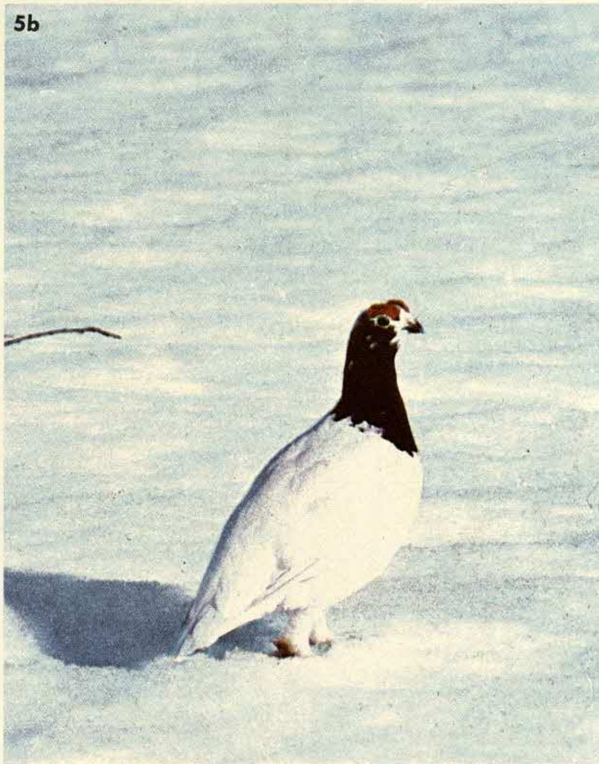


PTARMIGAN—The female ptarmigan shown in Illustration 5a has white winter plumage that blends in well with the snow and helps to hide her from the hawks and snowy owls that prey on ptarmigan. Illustration 5b shows the male who has begun to molt and acquire his summer plumage.

5a

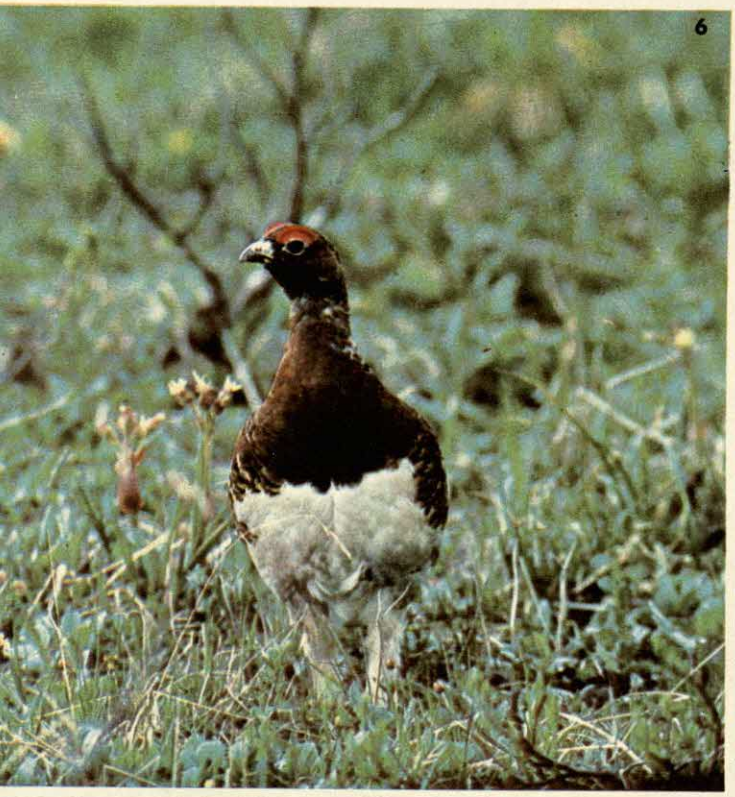


5b



SUMMER PLUMAGE—The ptarmigan wears brown and white plumage in the summer when the snow has completely melted. Ptarmigan do not migrate very far but live throughout the year in the Arctic (Illustration 6).

CARIBOU—The caribou lives in Alaska, Northern Canada, and Siberia. A domesticated form, the reindeer, lives in Greenland and northern Eurasia. The fur may be black, brown, or tan; in winter the color usually is lighter. Herds of caribou migrate periodically. In the spring they move northward to the tundra and in autumn southward to the forests where they winter (Illustration 7).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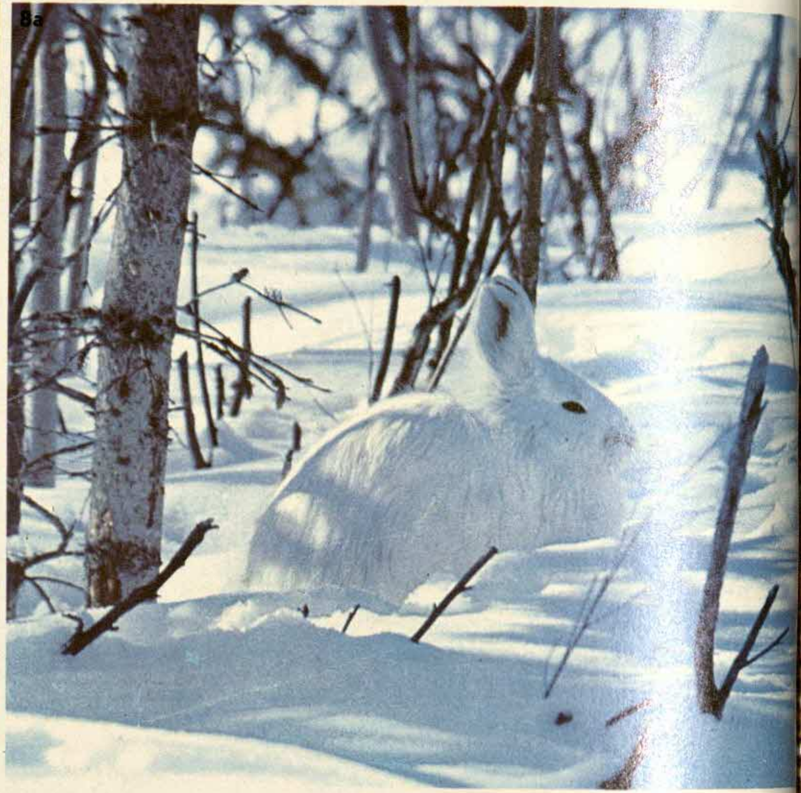
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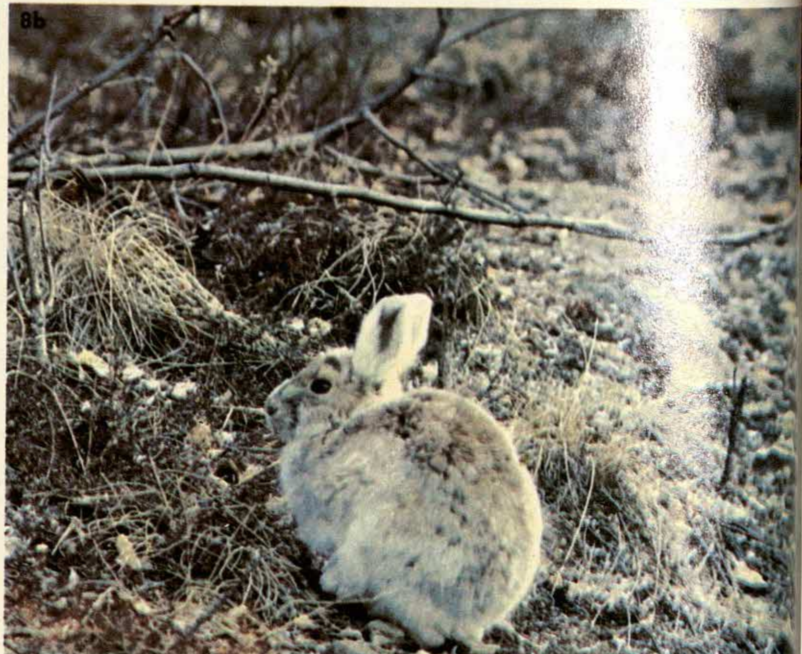
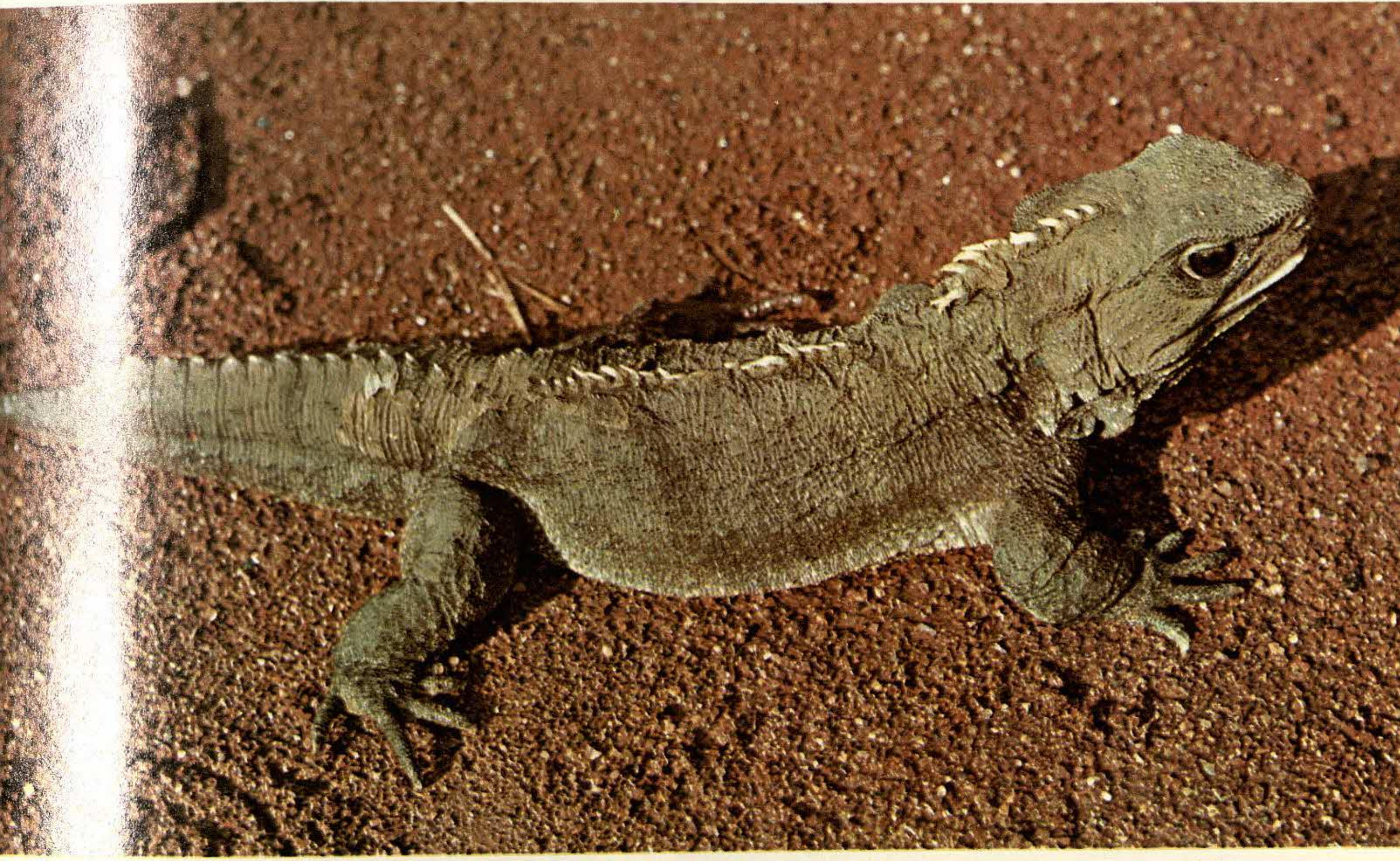

8b

SNOWSHOE RABBIT—The Arctic hare is sometimes called the snowshoe rabbit because the soles of its large hind feet bear thick fur that prevents the animal from sinking into deep snow. Illustration 8a shows the Arctic hare's white fur in the winter; in summer it is brownish-red. In spring and fall the coat is mottled, as shown in Illustration 8b.

THE FAUNA OF AUSTRALIA

a separate line of evolution

1



TUATARA—This lizardlike reptile (*Sphenodon punctatum*) lives on only a few small islands in New Zealand. The animal is about 60 cm (about 24 in.) long and rather stocky, with a crest of spiny tubercles that run from the back of its head to the tip of its tail. It is correctly considered a living fossil because it has some features typical of reptiles that lived millions of years ago and unknown in other living fauna.

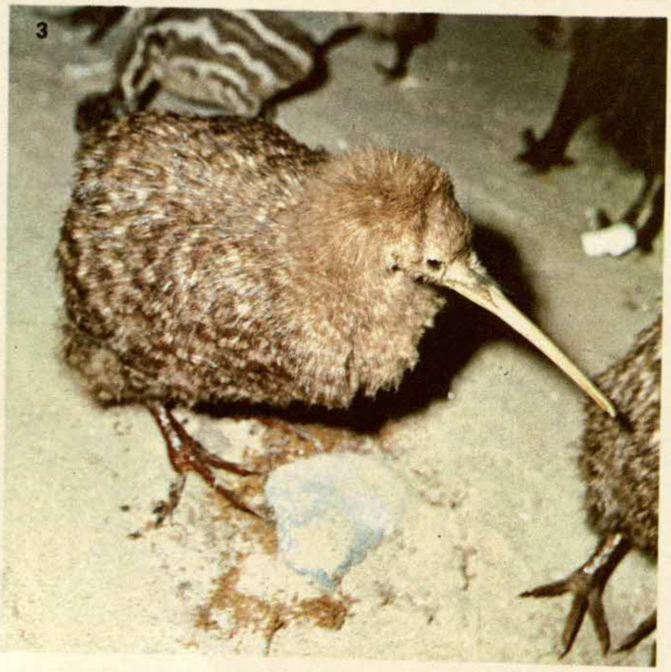
When newcomers arrive in Australia, they are usually impressed by the animals—so different from any known in other parts of the world. With only a few exceptions, the mammals native to the area are marsupials, and the only marsupials native outside the Australian region (which includes New Zealand, Tasmania, New Guinea, and nearby islands) are the opossums of North and South America. Marsupials resemble other mammals in having fur-covered bodies, in bearing live young, and in suckling the young. Their skeletal and muscular systems are very much the same as those of other placental mammals. Marsupials differ from other mammals in giving birth to offspring at an unusually early state of development.

COMPARISON OF PLACENTAL AND MARSUPIAL MAMMALS

The majority of mammals are placental mammals, in which the embryos develop into fetuses that reach a relatively mature state in the mother's uterus. The embryo is attached by an umbilical cord to the placenta, a flat portion of the uterus wall. During the time they remain in the uterus, the offspring are nourished with food and oxygen that reach them through the placenta and the umbilical cord. When they are born, some placental mammals—such as horses and antelopes—are well developed and are even able to walk within a few minutes or hours after birth. The young of other placental mammals—including puppies, kittens, and human infants—cannot walk for some time; but they do not have to be tended every minute by their mothers.

The marsupials do not have placentas (or at best have very rudimentary ones) and thus cannot provide adequate nourishment for embryos over a long period of development. The largest kangaroos, which are somewhat larger than human beings, bear their young after gestation periods of four to six weeks; in contrast, human mothers carry their babies for nine months. Within minutes of birth, marsupial infants crawl into their mother's abdominal pouch, or marsupium. Here each one takes one of the mother's nipples in its mouth. In some species the

2



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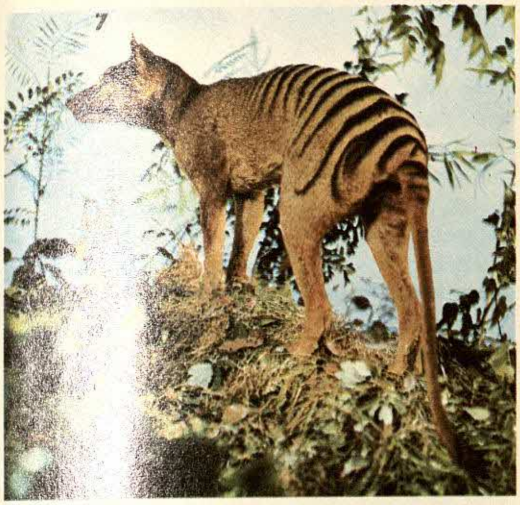

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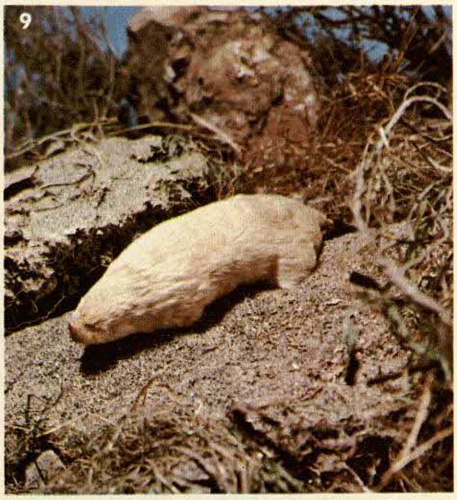

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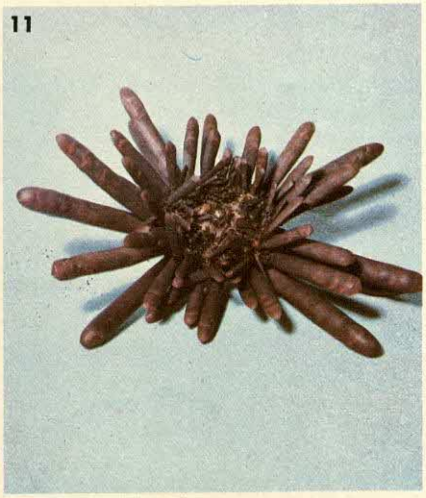


GIANT GRAY KANGAROO—Some specimens of this marsupial (Illustration 2) grow to a length of 3 m (about 10 ft).

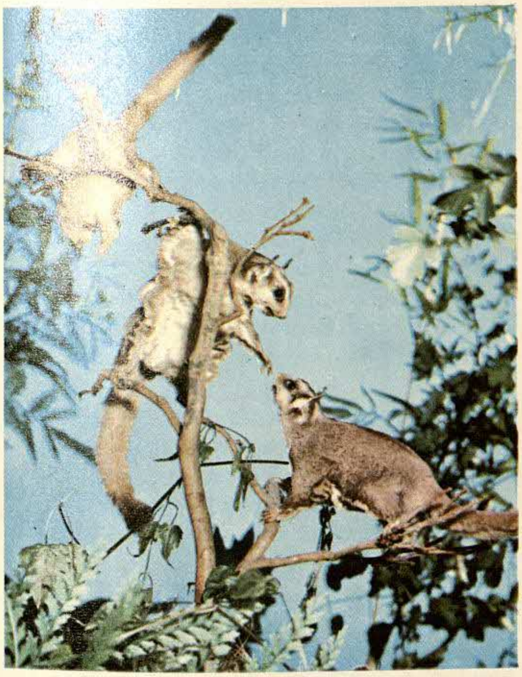
KIWI—A New Zealand bird, the kiwi (Illustration 3) has vestigial wings and cannot fly. Its long beak has nostrils at the end.

OPOSSUM—This marsupial (Illustration 4), which lives in trees, is much sought after for its soft fur.

ECHIDNA—A member of the monotremes, a group of primitive oviparous mammals, is the echidna, or spiny anteater (Illustration 5). Most of its body is covered with spines.

DUCK-BILLED PLATYPUS—This aquatic mammal (*Ornithorhynchus anatinus*) has a birdlike bill, webbed feet, and a fur-covered body (Illustration 6). Like the echidna, it lays eggs.

TASMANIAN WOLF—The largest carnivorous marsupial (Illustration 7) has a pouch that is quite small.



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SUGAR GLIDER—The tree-dwelling sugar gliders (*Petaurus breviceps*) in Illustration 8 resemble squirrels in size and agility.

MARSUPIAL MOLE—This burrowing marsupial (Illustration 9) has only vestigial eyes and its ears are not visible. Its small pouch opens to the rear.

KOALA—An arboreal marsupial that looks like a teddy bear, the koala (Illustration 10) eats only the leaves of eucalyptus trees.

SEA URCHIN—This curious species of sea urchin (*Heterocentrotus trigonatus*) dwells in the Pacific Ocean waters around the Gilbert Islands (Illustration 11).

young actively suck milk from the mother, while in other species the mother forces milk into their mouths. The infants continue their development in the pouch as placental mammals would in the uterus. When they reach a stage of maturity corresponding roughly to the stage at which placental mammals would be born, they emerge from the pouch; but they return to it frequently for rest or for security until they are completely independent of the mother.

EVOLUTION OF MARSUPIALS

Formerly, the marsupial mammals were believed to have evolved much earlier than the placental mammals, but it is now thought that both types developed from the pantotheres, a group of primitive mammals that lived during the Jurassic period (about 180 to 135 million years ago) and then became extinct. Fossil evidence indicates that marsupials once had a worldwide distribution. Placentals were also widespread, but except for rodents and some marine mammals, the only placentals in Australia are man and the animals he brought with him.

A great deal of geological evidence indicates that all the continents of the world once were part of a single large landmass and that during the Cretaceous period (about 135 to 70 million years ago) this landmass broke up into several pieces that slowly drifted apart and formed the continents as they are today. The first marsupial and placental mammals existed on this landmass before it broke up, but they probably did not reach southeastern Asia until a large gap of water separated the Australian portion from the rest. There were many islands in the water, and it is believed that the marsupials reached Australia by island-hopping—sometimes by swimming but probably more often by clinging, stranded, to logs or tree branches that drifted from island to island. Presumably marsupials were more efficient at island-hopping than were the placentals —although it is not clear why. Rodents seem to be the only placentals that reached Australia in this way.

Except for its easternmost portion, Australia is an arid land, much of it either desert or grassland. Forests, composed largely of eucalyptus trees, occupy the eastern region. Isolated on this large continent, without competition from placental mammals, the marsupials were able to develop into many species adapted to life in the various ecological niches of Australia. In other parts of the world the marsupials gradually declined in numbers and became extinct, for they were not able to compete with the more successful placentals. It is interesting to note, however, that the evolution of the Australian marsupials has in general paralleled that of placentals. There are marsupial "cats," "mice," and "moles" that look similar to placental cats, mice, and moles and have the same general life habits. The koala, which looks like a child's teddy bear, is a marsupial that climbs trees in a manner similar to that of placental bears; and the Tasmanian wolf is a doglike carnivore. The phalangers, or sugar gliders, are tree dwellers that resemble flying squirrels. Like the cattle and antelope that graze on the plains of other continents, the marsupial kangaroo is a grass eater; but the kangaroo, with its large hind legs looks little like its placental counterpart.

OTHER ANIMALS OF THE AUSTRALIAN REGION

Australia has at least 500 varieties of birds and reptiles that are not found anywhere else. There are about 50 species of parrots, ranging from small nectar-feeders to large, heavy, seed-eating and cone-eating cockatoos. The honey eaters, nectar-feeding songbirds, have radiated into 67 species. The spectacular lyrebird and the bowerbirds are dancers. The lyrebird is so named because the male's long tail feathers resemble a stringed lyre when he raises them. In the breeding season, he builds a mound of earth on which he then performs a ritual dance. The lyrebird is renowned for its gift of mimicry. Most bowerbirds court by dancing in and out of a bower of sticks prepared for the purpose.

Two large flightless birds of Australia are the emu and the cassowary. The emu, which is of the same general size and appearance as the ostrich, inhabits northern, southeastern, and southwestern Australia. A bird similar to the emu, the moa, lived in New Zealand until it became extinct in historical times. Cassowaries are confined mostly to New Guinea and nearby islands, but one species reaches northeastern Australia. The cassowary is one of the few birds that can easily kill a man. It has powerful legs; and on each of its feet, the innermost of three toes is fitted with a long, straight, stiletto-like nail. Cassowaries are characterized by helmets, or casques, on their heads and by rudimentary wings that they use to fend off obstructions as they run through the forests at speeds up to 30 mph.

New Zealand is the home of the kiwi, a peculiar flightless bird having feathers that look like shaggy hair and nostrils at the tip of its long curved beak rather than near the base of the beak as in most other birds. Kiwis are closely related to the extinct moa. For its size, which approximates that of a large domestic fowl, the kiwi lays the largest egg of any living bird.

The Australian region includes in its reptile fauna about 130 snake species, about 240 kinds of lizards, 13 fresh-water tortoises, and two crocodiles. Inhabiting rivers of the sparsely populated north, the crocodiles are no problem to man. Although a high proportion of the snakes are venomous, only a few species are dangerous to man. New Zealand has no snakes. On a few small islands in New Zealand survive some colonies of tuataras—primitive reptiles that have no close living relatives anywhere in the world. One of the most bizarre reptiles in Australia is the frilled lizard. It has a fold of skin around its neck that hangs like a cape around the shoulders until the lizard is angered or frightened; then the fold stands up like a huge ruff.

Australian frogs include a diversity of ecological types. The desert water-holding frog is an example of extreme adaptation to environment. When the water holes that it frequents dry up, the frog buries itself a foot or more beneath the bed, fills itself with water until it looks like a tennis ball, and, in a miniature chamber partly sealed by dried mucus, survives until the next rain. The tiny black and yellow corroboree frog, which lives above 5 thousand ft, can survive under the snow for up to five months.

In the rivers of Queensland lives the strange Queensland lungfish, which has both gills and lungs. Arguments continue as to whether it is fish or mammal.

THE CORAL REEF | marvelous architecture in the ocean

The coral reef, with its great variety of structures and colors, may be considered the most spectacular of nature's wonders; yet it is built by tiny animals: polyps with near-microscopic dimensions. The cylindrical body of a polyp has a mouth opening circled by tentacles that move in the water to collect food and discard refuse. The lower part of the cylinder, stemmed and cuplike, is attached to the rocky or sandy bottom or to another coral; it has a calcified skeleton. Only during the brief larval stage are the coral animals free to move around. Polyps are carnivorous, feeding on small crustaceans, worms, and protozoa. The tentacles often paralyze prey by means of stinging capsules (nematocysts).

Corals belong to the class Anthozoa, in the phylum Coelenterata. They are related to the sea anemones and belong to several orders, including the fan corals, Gorgonacea, and the true corals, or stony corals, Madreporaria (Scleractinia). They range from the cold, polar seas to the tropics, but their optimal environment is in the tropical and subtropical seas. Only where the water is clear and sunlit to about 30 m (about 100 ft) and the temperature of the ocean seldom ranges below 20° C (68° F) can the reef-building true corals construct their reefs. These conditions do not occur outside the region between the 22nd parallels.

Corals need sunlight because the presence of microscopic algae in their tissues is essential to their growth. In a symbiotic relationship with the coral polyps, the algae, by photosynthesis, contribute oxygen to their hosts' metabolism. Besides light and warmth, coral polyps have other requirements: the water must be moving, and it must be relatively free of silt so that the corals will not be smothered in mud.

Considering that coral polyps can live only on relatively shallow bottoms where sunlight penetrates, the existence of undersea coral cliffs at a depth of over 2,400 m (over 8,000 ft) has been somewhat of a mystery. To explain these formations, a hypothesis first put forward by Charles Darwin has gradually attained wide acceptance. It is thought that the coral islands (atolls), whose bases lie at great depth, have been formed by both a gradual lowering of the ocean floor (from volcanic causes) and an elevation of the ocean level. Consequently, new layers of corals have constantly grown on the older ones, which were submerged deeper by the forces of the ocean and the Earth's crust. As a result, the corals of an atoll are living on top of an immense tower, built from the bones of their ancestors—a monument to the continuity of coral life.

A CORAL CONSTRUCTION—The Cayo Avalos is one of the 1,600 atolls off the coast of Cuba. An atoll is a coral island consisting of a ring-like reef surrounding a central lagoon. Most atolls have developed on the summits of submerged volcanoes; corals and algae are responsible for their construction.

Most atolls are formed of circular reefs enclosing quiet lagoons. The reef that forms the island is at the center of a submerged coral platform with a somewhat higher edge, the barrier reef, over which the ocean's waves break. Beyond the barrier reef the coral formation drops steeply to the ocean floor. Barrier reefs also parallel some continental coasts in the tropics and the coasts of some larger islands, such as Cuba and Celebes (in Indonesia).

The greatest coral reef in the world extends over a surface of almost 259,000 sq km (about 100,000 sq mi) and has a length of almost 1,770 km (about 1,100 mi). It is the Great Barrier Reef, which stretches from the Murray island group along the northeast coast of Australia to the Bunker group, off Gladstone, Australia. This reef rises almost 2,400 m (about 8,000 ft) from the ocean floor, where the calcareous formations indicate an age estimated at 2 to 3 million years.

Evidence of coral-reef building, however, goes much farther back than that. For example, limestones and dolomites containing great coral colonies formed as early as the Devonian period (roughly 400 million years ago) indicate that a shallow sea once existed over an area including southwestern Ontario, Michigan, Wisconsin, and Indiana. Calcareous rocks formed by reef-building corals of the Devonian and later geological periods are found in Europe, Asia, and other parts of the world. In these locations, now mountainous in certain places and with a cool climate, once stretched crystal-clear tropical seas in which enormous coral colonies thrived.

Even in the primordial coral reefs of the Devonian, life was abundant. Today's coral reefs are unrivaled in their teeming variety of life in all its brightest colors and most intricate forms. The forms of the corals may vary somewhat according to depth; they may have branches like candlesticks (*Acropora*), like fans (*Gorgonia*), like clubs (*Stilophora*), or growths like the heads of mammals (*Maeandra*); together they grow in thickets and forests resplendent with striking colors. A coral reef includes structures resembling flags, flowers, trees, staghorns, mushrooms, or skyscrapers, together with tortuous sculptures with a maze of caves and meandering gullies.

Other colonial animals, like the Bryozoa and the sponges, live among the corals, as do tunicates, numerous mollusks, sea anemones, starfish, sea urchins, crabs, crayfish, and a great variety of fish. No other ocean biome has such a density and variety of population. The optimal ecological conditions caused life to proliferate until it attained a complex biological equilibrium, based on the ne-

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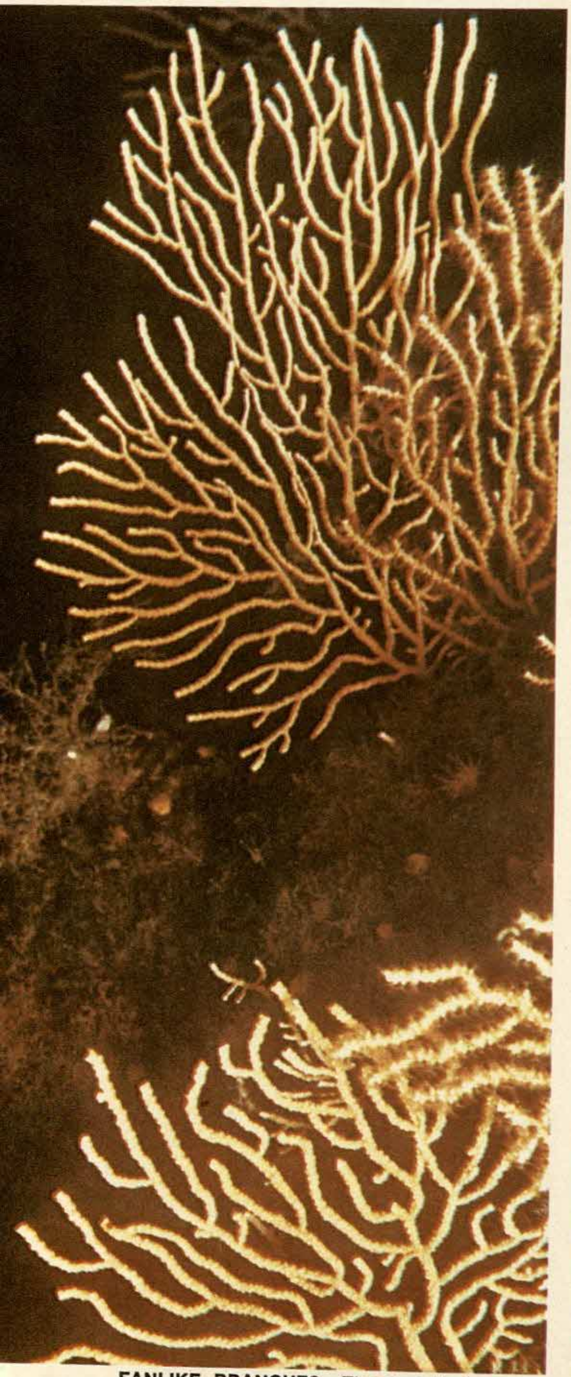

FANLIKE BRANCHES—These delicate structures are colonies of *Eunicella verrucosa*, a member of the order of fan corals (Gorgonacea).

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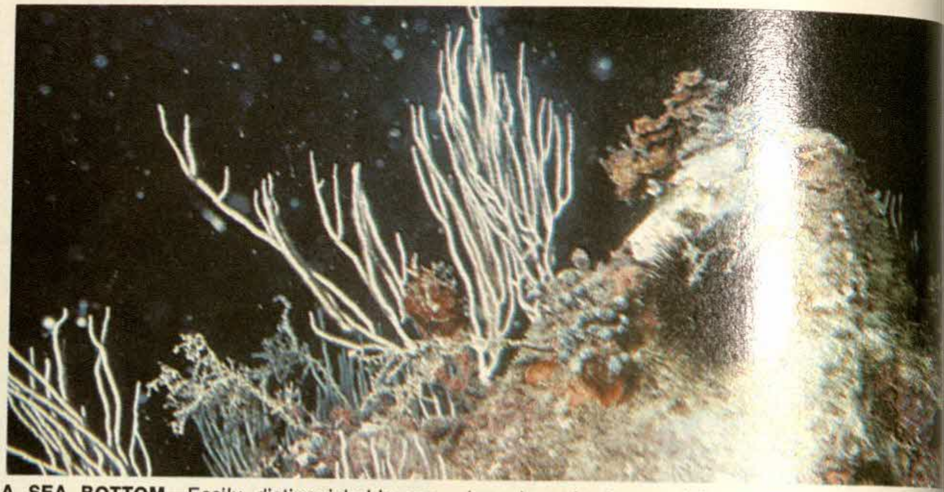

A SEA BOTTOM—Easily distinguishable are a large sea urchin and the thin, flexible branches of a fan coral (in this case *Eunicella cavolini*).

cessity for each animal to find prey and defend itself against aggression. The need for mimicry among the brightly colored corals has stimulated the survival of brightly colored animals.

Starfish, for example, are brightly striped or spotted in red, yellow, or blue; and crayfish, elsewhere usually rather neutral in color, present varicolored stripes on a red or green background or yellow spots on a blue background. Some crabs have chosen another method of protective coloration: they attach sponges, sea anemones, algae, or even corals to their bodies. The fishes, too, are often showy with bright colors.

The sizes of the animals are also adapted to the coral environment. Slow-moving or sessile animals may grow quite large: old oysters may weigh seven pounds or more, and some bivalves (for example, *Tridacna*) weigh over 1,700 kg (about 800 lbs). The fishes are usually quite small; they move quickly through the tunnels and mazes of the coral forest. Larger predators, such as the barracuda, the sting ray, and the moray, also live in the coral community, however.

Because the water of the coral reef

ANGELFISH—This elegant and brightly colored member of the genus *Angelichthys* belongs to the family of the butterfly fish (Chaetodontidae). Its habitat is the coral reef.

4

contains very little plankton, most fish are carnivorous, as are the three best-represented families, the wrasses (Labridae), the butterfly fishes (Chaetodontidae), and the damselfish (Pomacentridae), all of the perch order. When food is scarce, however, these fish easily adapt themselves to a vegetable diet. Another adaptation in diet is represented by the parrot fish (family Scaridae), which have four molars and a powerful beak to crush and ingest the hard coral rock in which their food, algae, abounds. One variety of trigger fish feeds on the coral polyps.

Highly specialized adaptations are widespread in the community of the coral reef. The damselfish, for example, spends most of its life among the tentacles of the sea anemone, an organism venomous to all other species. The shrimpfish (Amphisilidae) lives among the poisonous spines of the sea urchin. The scorpion fish (*Scorpaena*) and the frogfish (Antennariidae) have appendages and wrinkles that blend them in with the coral environment. To confound aggressors, the butterfly fish (*Chaetodon*) have a design of big eyes in their tails. The flounder, who spends its life lying on the sandy bottom, has its mouth on one side and its eyes close

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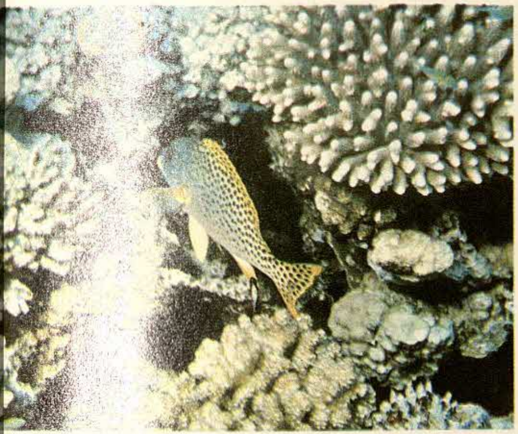

DELICATE TUFTS OF STAGHORN CORALS—One of the showy fish that populate the reef winds its way through the formations of the staghorn coral (*Madrepora*), a true coral that abounds in the sunlit waters of the tropical seas.

MEADOW OF *ASTROIDES CALYCULARIS*—This true coral of the Mediterranean forms bright yellow patches on the sea bottom.

6

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SPIRASTRELLA CUNATRIX — This animal (*lower left corner*) is one of the many sponges that lives in the coral reef biome. The rounded coral in the center is a poritoid.

EGGS OF THE CUTTLEFISH—These eggs look like a tuft of feathers between the branches of fan corals.

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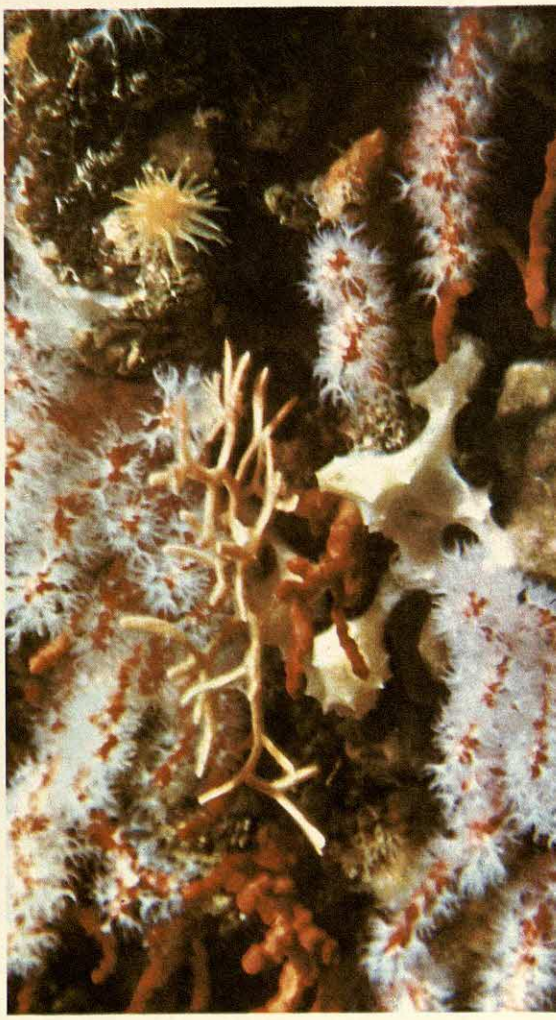
CORALLIUM RUBRUM—This colony of blood coral (a fan coral) resembles a flowering branch because the white polyps extend their tentacles like rays. Blood coral is the source of precious coral stone.



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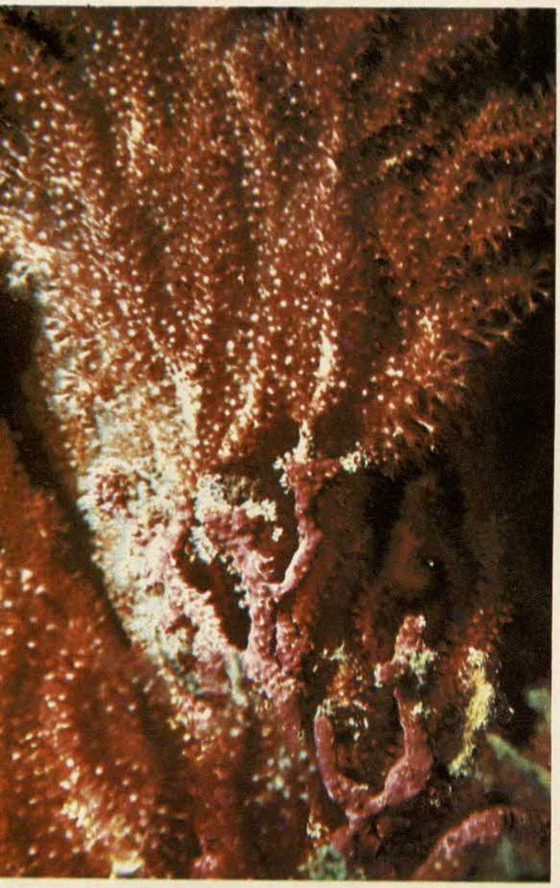

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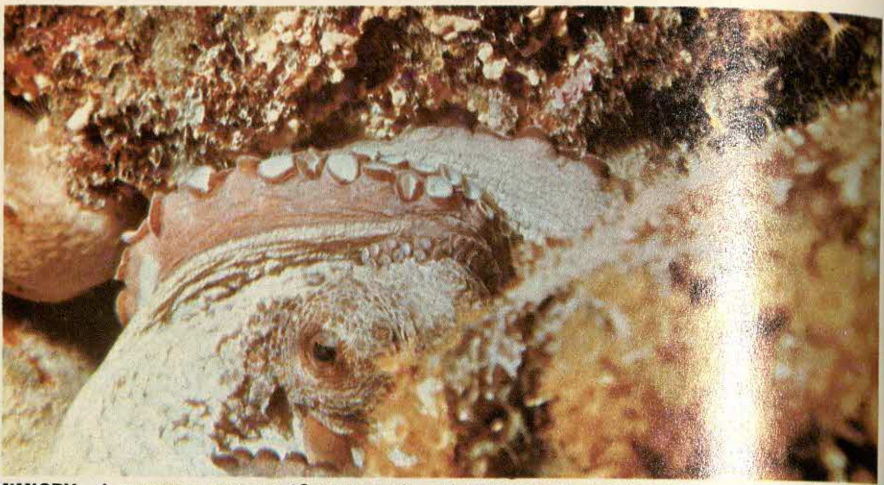


MIMICRY—A common octopus (*Octopus vulgaris*) hides in the orange-yellow formation of *Astroides calycularis* (see also Illustration 6). The eye is clearly visible, as is part of a tentacle with its suction caps that repeat the patterns of the surroundings.

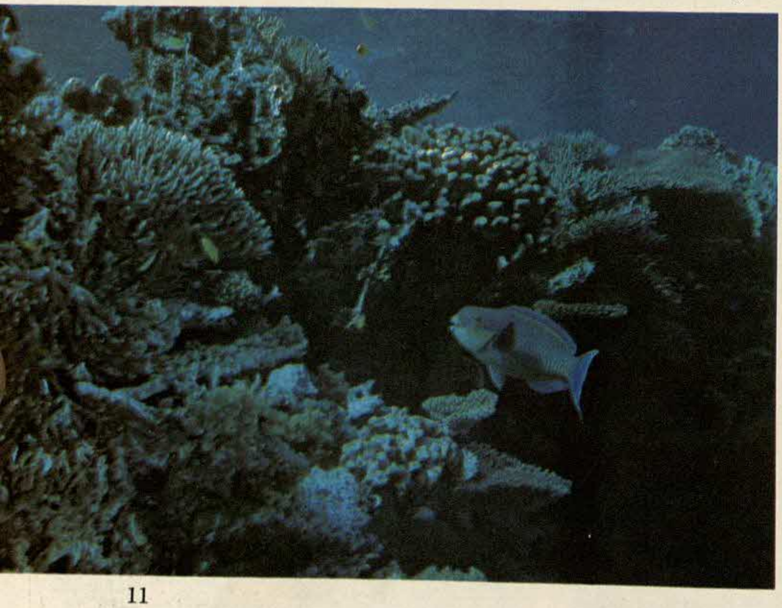
together on the upper body surface.

The defense systems of many coral reef animals are formidable and often include the use of potent venoms. Among the poisonous species are the lion-fish (*Pterois*), the scorpion fish, and several sea urchins and starfish who, with their poisonous darts, can cause a temporary paralysis even in man. The most dangerous animal is the stonefish (*Synanceja*) of the western Pacific. From its sticky and wrinkled back project 13 straight spines, each provided with two glands that produce mortal venom for which no antidote is known. The stonefish lies on the bottom, often partly covered with sand, where it can easily be stepped on; hence it is greatly feared.

Thus, one of the most interesting biotic communities is based in the coral structures of the lucid tropical seas. But, while the coral polyps build their complicated structures, many other forces break down the coral reef. The ocean waves hammer the sides of the reef that are exposed to the open sea; the tides scour the corals; the torrential tropical showers kill the polyps by excessive dilution of the salinity of the lagoons. Among the living organisms that weaken the coral are algae and the mollusks that make holes to take refuge in, thereby contributing to the dismantling of the coral rock by the seawater.

BRANCHES OF *PARAMURICEA CHAMALEON*—This fan coral sometimes forms a veritable forest of bright red branches. In the lower foreground is a colony of *Alcyonium coralloides*, a red tuberous coral related to dead man's finger (order Alcyonacea).

PARROTFISH—With its horny beak the parrotfish crushes and swallows coral rock, which abounds in algae that nourish the fish.



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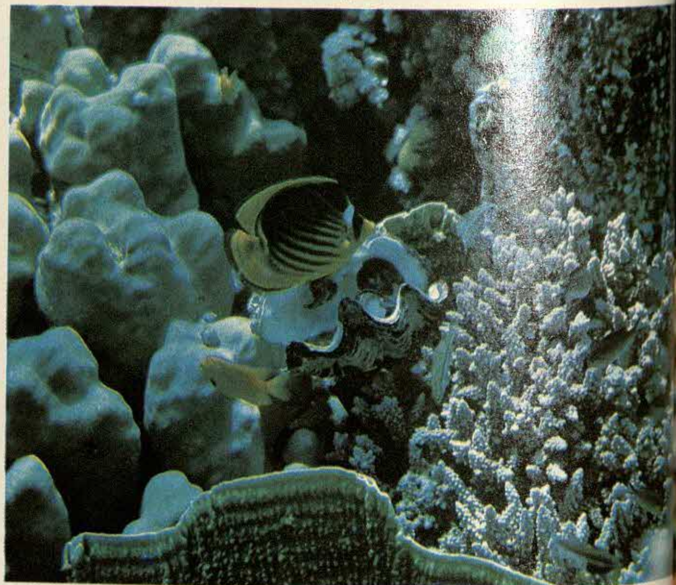

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BUTTERFLY FISH—This member (*Chaetodon fasciatus*) of the family Chaetodontidae has colors that are well adapted to the environment it inhabits. Also visible are the open shell of a mollusk and several pebble- and fanlike coral structures.

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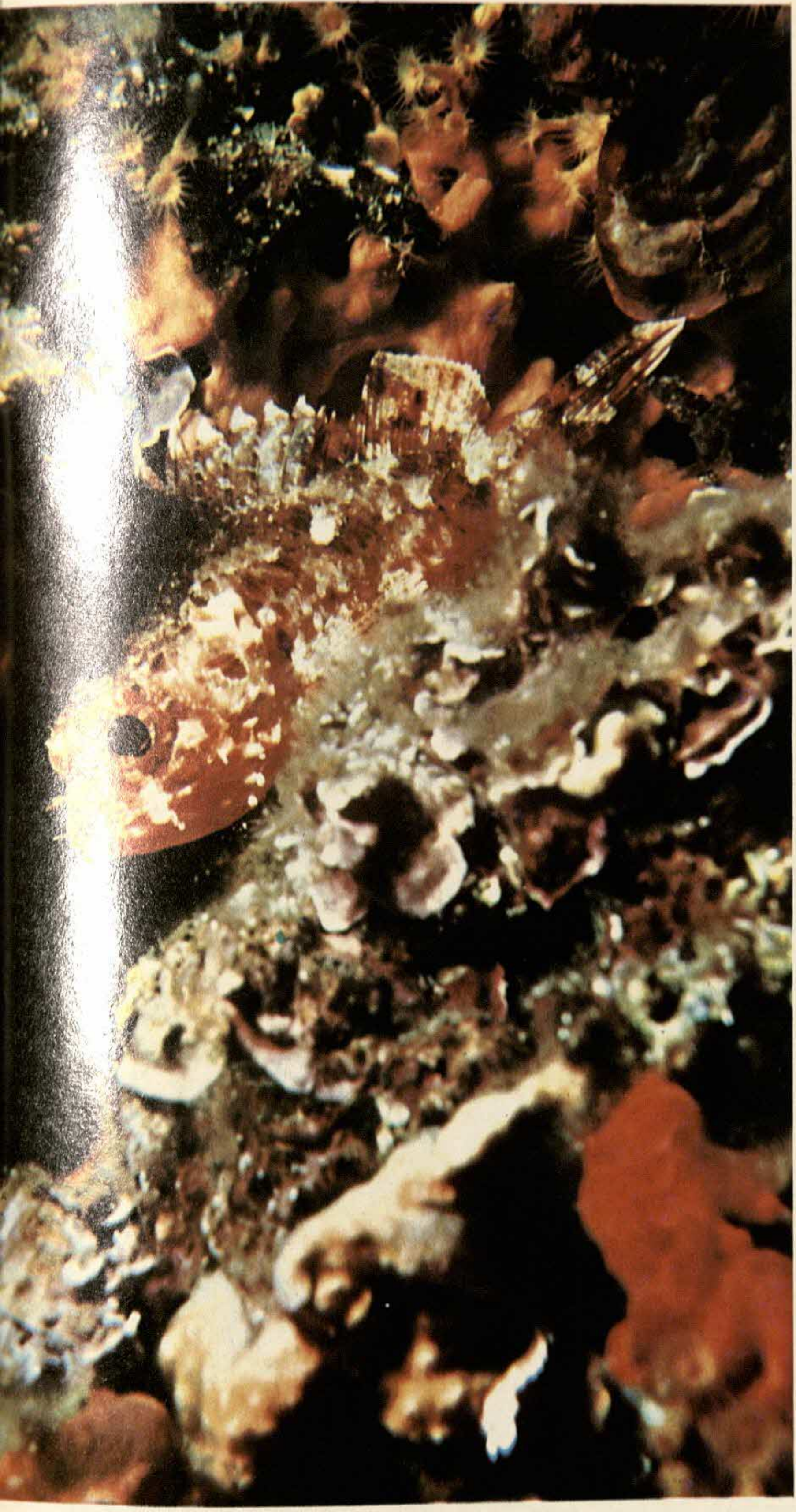

SCORPION FISH—The wrinkled body of the *Scorpaena ustulata* has poisonous spines and many appendages that look like algae and serve to camouflage the fish. The spines are defensive weapons, and the appendages serve to lure small fishes on which the scorpion fish feeds.

EGG OF A STINGRAY—The egg is enclosed in a capsule with tendrils that attach to the corals.

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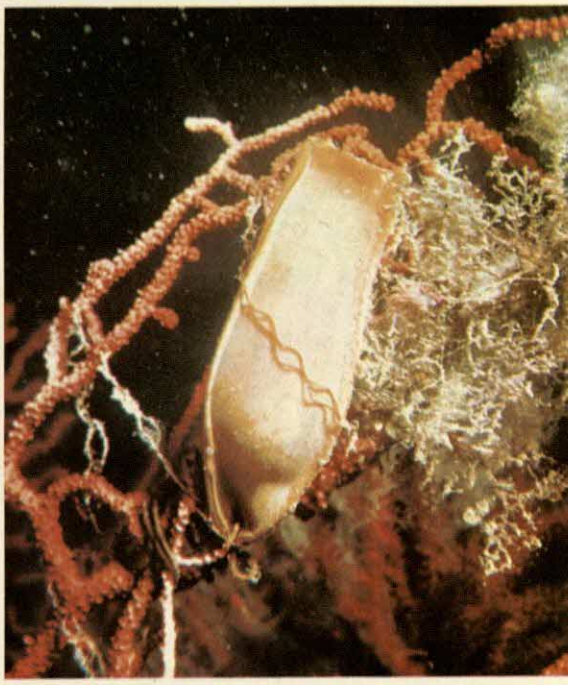

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OCEAN BOTTOM—Red-violet branches of *Paramuricea chamaleon* and *Alcyonium coralloides* (see also Illustration 10) flank a passing school of small fishes.

SPECIATION

the origin of new species

Before the acceptance of the theory of evolution, a species—the basic biological unit—was defined only on the basis of morphological and physiological characteristics. Each species was considered the result of a separate act of creation.

But when Charles Darwin published his theory of the origin of new species from pre-existing species—a theory that has been supported repeatedly by research in genetics—the definition of species changed to: that group of individuals that are similar in all essential characteristics, that are interfertile, and that sexually reproduce fertile individuals similar to themselves. Each species is thus understood to be a breeding unity; that is, a group of individuals that can be interbred normally and regularly. Species are no longer considered static forms of life but dynamic forms that originated from the differentiation of races belonging to a single original species.

Each species, then, remains distinct from species closely related to it not only because of its morphology but principally because of mechanisms of reproductive isolation that tend to prevent breeding between individuals belonging to different species—even those that are very similar. This reproductive isolation is essential for the conservation of the species; for if it did not exist, individuals belonging to different species could easily interbreed, thus contaminating their genetic heritage and giving rise to descendants with intermediate characteristics belonging to neither of the two parent species.

ISOLATING MECHANISMS

Among the numerous isolating mechanisms, the most important probably are ecological isolation, seasonal isolation, and sexual isolation.

In the case of ecological isolation, even though the members of two or more different species are very similar and inhabit the same geographic region, they

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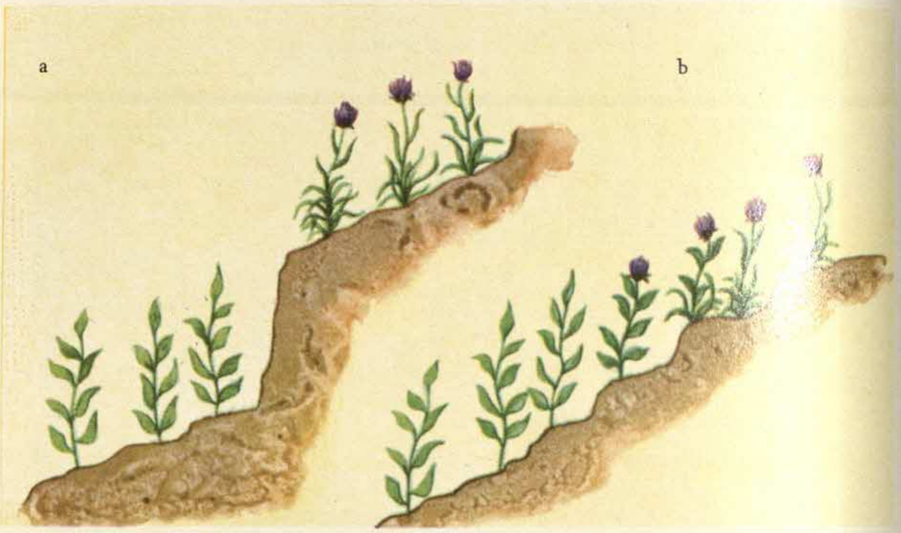

ECOLOGICAL ISOLATION—The species *Tradescantia subaspera* and *Tradescantia canaliculata* grow in very different habitats, the first in shady zones at the base of rocks, the other atop the sunny spurs of rock. Usually the two species have no possibility of interbreeding (Illustration 1a). However, they can hybridize in places where the two habitats overlap (Illustration 1b).

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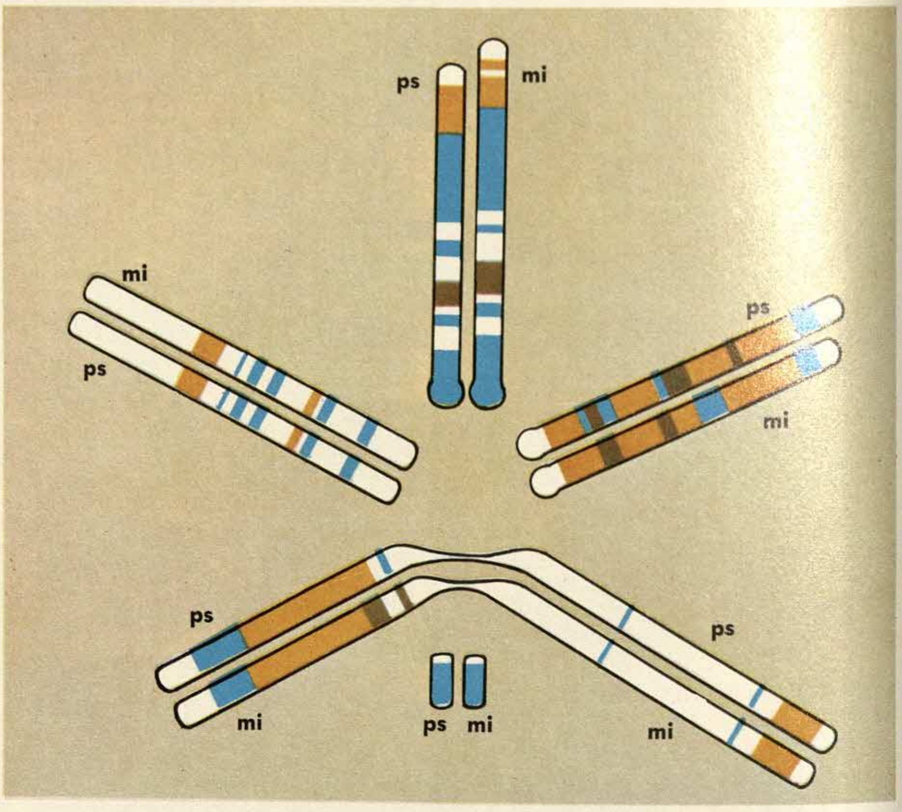

TWO VERY SIMILAR SPECIES—The illustration compares the chromosomes of *Drosophila pseudoobscura* **ps** with those of *Drosophila miranda* **mi.** The white areas represent those portions of chromosomes in which the genes of both species correspond. The brown areas indicate the portions in which translocations occur; the orange areas indicate the portions with inversions, and the blue areas represent portions that do not correspond at all.

live in different habitats; thus, they have practically no opportunity to meet and interbreed. For example, two similar species of plants—*Tradescantia canaliculata* and *Tradescantia subaspera*—grow, respectively, atop rocky spurs in sunny zones and in shady zones at the bases of the same rocky spurs. Similarly, two species of small flies—*Drosophila pseudoobscura* and *Drosophila persimilis*—which are found on the western coast of North America from Alaska to Guatemala, prefer to live at different altitudes, one high and one low.

Seasonal isolation occurs if individuals belonging to similar species have breeding seasons at different times of the year. The leopard frog and the bullfrog are common throughout much of eastern North America, but the leopard frog breeds in spring and the bullfrog breeds in summer.

Where sexual isolation exists, males and females belonging to different species, even though living in proximity, are not attracted to each other but mate exclusively or chiefly with individuals of the same species. Many species have peculiar calls, coloration, or courtship patterns by which they recognize potential mates of their own species; they do not respond, however, to the signals of other species.

THE MECHANISM OF SPECIATION

Once it was believed that all living plants and animals subdivided into species had their origin at the moment of the creation of the world and had remained unchanged in time. It was held, in other words, that species were static entities.

Modern genetics has demonstrated, however, that species are dynamic groups and that speciation is essentially the result of the establishment of reproductive isolation between groups of individuals that once belonged to the same species but changed with mutations or other alterations of the genetic material.

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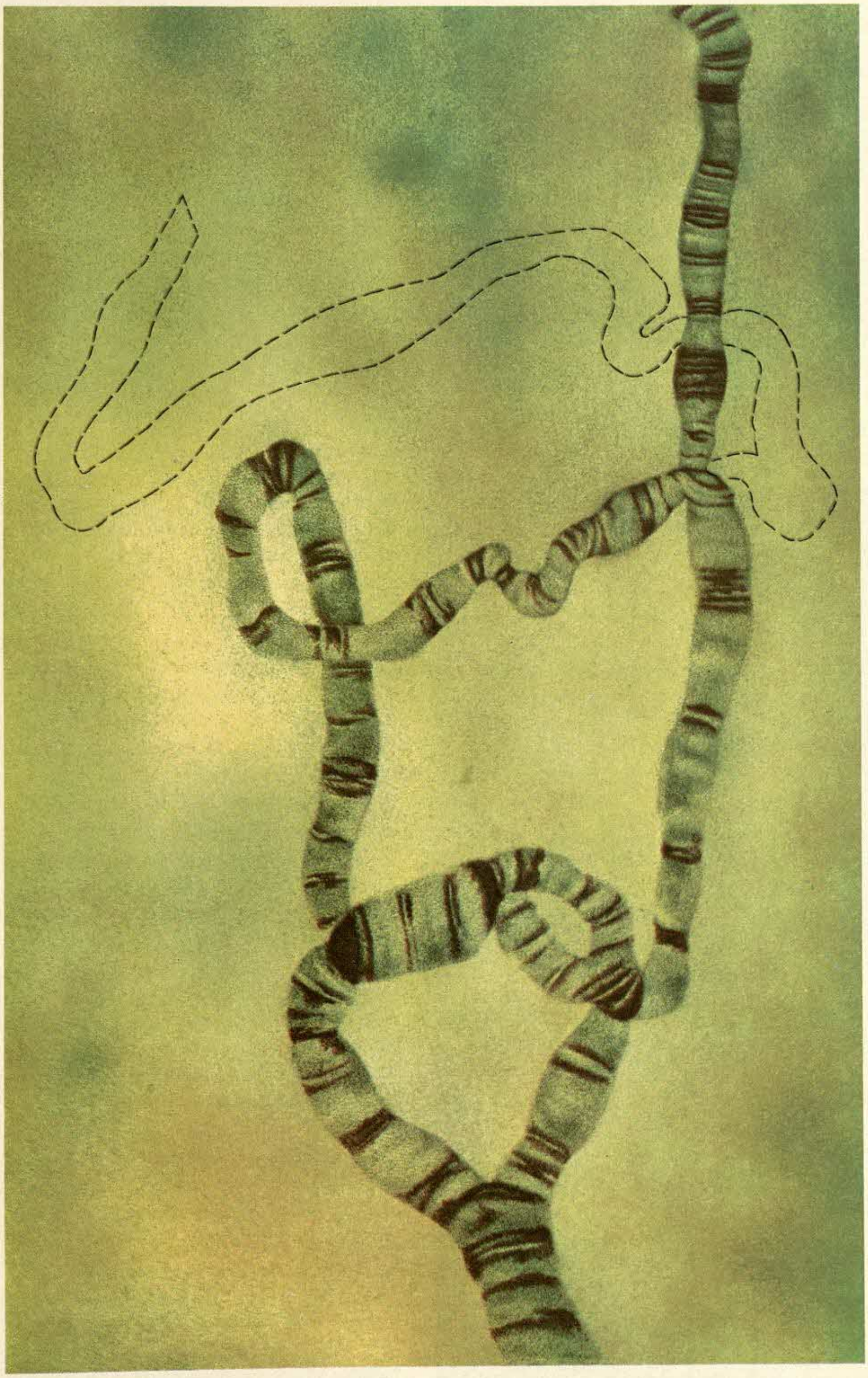

THE PAIRING OF HOMOLOGOUS CHROMOSOMES—These chromosomes pairing during meiosis belong to a hybrid of the species *Drosophila pseudoobscura* and *Drosophila miranda.* Homologous areas where the genes correspond exactly are united and appear very thick. Those portions with completely different genes remain separated. Loops are caused by the presence of inversions in one or both chromosomes.

Consider a particular population formed of individuals having the same genetic heritage and inhabiting a rather large region. After a certain period of time, this population will no longer have a homogenous genetic structure but will consist of several isolated groups (races) that have evolved as a result of natural selection and that have become adapted to the several different kinds of environments found in that region. These groups differ from one another in the genes they possess, in the disposition of genes on the chromosomes, or in the numbers of chromosomes. As a result of these variations in genetic heritage, the individuals belonging to different races (but to the same species) are suited to living in different environments. They may also present somewhat different external characteristics. However, they are still capable of breeding among themselves and producing fertile descendants.

The geographical isolation to which they are subject, however, makes such interbreeding improbable; on the other hand, it permits these races to become ever more differentiated as they adapt even further to their environments. They accumulate new genetic differences and eventually become species.

RADISH AND CABBAGE—*Raphanus sativus* (radish) has white or pink flowers and thick pods (Illustration 4a). *Brassica oleracea* (cabbage) has yellow flowers and thin pods (Illustration 4b). These two species are usually difficult to interbreed. When hybridization does occur, either sterile diploid hybrids or fertile allotetraploids are produced.

4a

4b

POLYPLOIDY

The genetic changes that cause the rise of new species are of various types: they may consist of a variation in the number of chromosomes, the mutation of single genes, or alterations in the order of the genes (structural rearrangement of the chromosomes).

Changes in the number of the chromosomes may arise as a result both of polyploidy and of translocation. Polyploidy is the possession of three or more complete monoploid sets of chromosomes—a condition common in plants but very rare in animals. Triploid cells have three sets of chromosomes, tetraploid cells have four sets, and so forth.

Polyploidy may arise naturally or artificially. Ordinarily each cell division and nuclear division is accompanied by the duplication of chromosomes. Occasionally the duplication is not followed by the division of the nucleus and the cytoplasm; as a result, the number of chromosomes in the cell is doubled. If this occurs in a diploid organism, a tetraploid cell results; if it occurs in a tetraploid organism, an octoploid cell is produced, and so forth. The application of colchicine is used to induce polyploidy artificially.

Autopolyploidy occurs when three or more sets of chromosomes from one species are present in the nuclei of an individual, which then is called an autopolyploid. Allopolyploids are hybrids that have complete sets of chromosomes from two (rarely more) parent species. Often they have two identical monoploid sets from one parent species and two more identical monoploid sets from the other species. No distinct division exists, however, between autopolyploids and allopolyploids, because the allopolyploids usually derive from the hybridization of species that are quite similar and, therefore, present characteristics that are almost indistinguishable from those possessed by the autopolyploids.

In most cases, plant autotetraploids differ from the diploids from which they originated in several characteristics—such as greater hardiness or larger stems, leaves, and flowers—because of the greater size of their cells. Furthermore, they can reproduce, but they often have fewer offspring than diploid individuals. Tetraploids produce diploid gametes, not monoploid gametes as do diploid organisms. Two tetraploid parents (or a self-pollinated tetraploid plant) produce tetraploid offspring. Triploid individuals result from a cross between a tetraploid parent and a diploid parent.

Although there exist many mechanisms of reproductive isolation that tend to prevent breeding between individuals of different species, occasionally hybridizations occur in nature. Almost always, however, the offspring of such interbreeding are not fertile. This is the case in hybrids of the cabbage (*Brassica oleracea*, with a diploid number of 18) and the radish (*Raphanus sativus*, which also has a diploid number of 18). In these hybrids the 9 chromosomes from the cabbage parent cannot pair with the 9 chromosomes from the radish parent during meiosis, and so viable gametes are not produced. Nevertheless, in some cells the set of chromosomes occasionally undergoes doubling. These cells become tetraploids with 36 chromosomes: 9 pairs from the cabbage and 9 pairs from the radish. Then pairing of identical chromosomes is made possible in meiosis, and a second generation of fertile hybrids may occur. These allotetraploids, called *Raphanobrassica*, constitute a new species. They can reproduce themselves normally, but they are almost completely isolated from their progenitors, the cabbage and the radish. It is difficult to cross them with either parent species, and even if such a cross is made, the descendants are triploid hybrids, almost always sterile.

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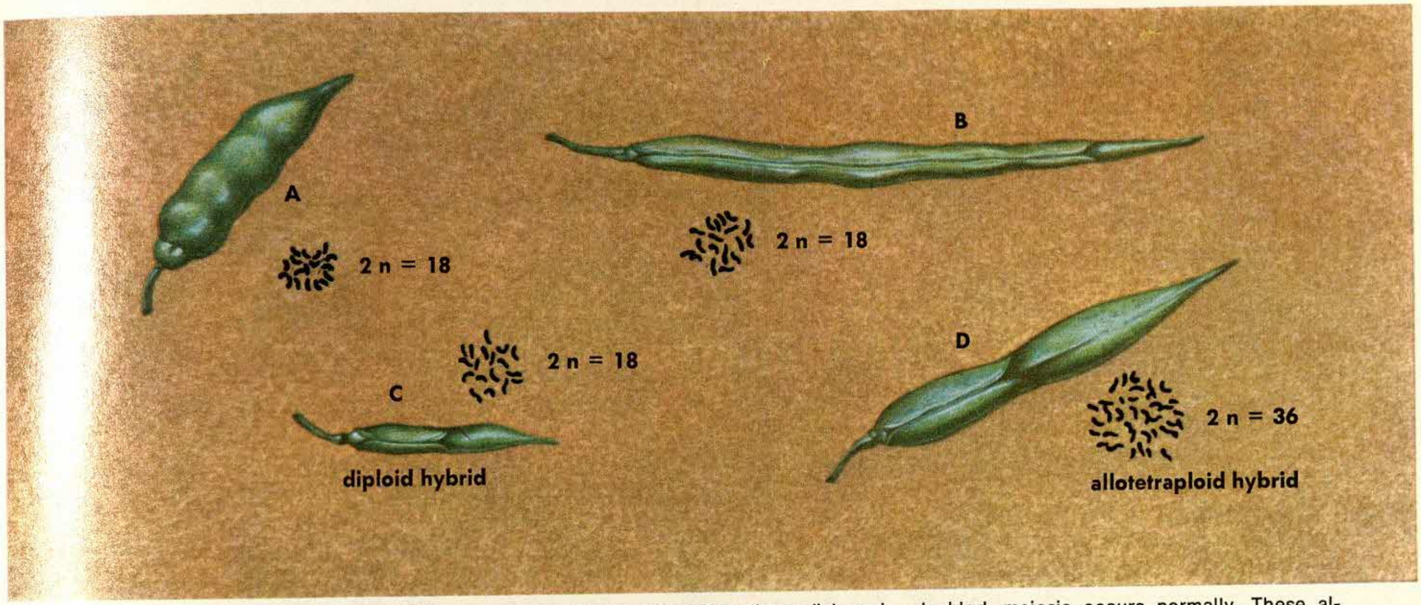

DIPLOID HYBRIDS AND ALLOTETRAPLOIDS—The cross between the radish **A** and the cabbage **B**, which are represented in this illustration by pods and their sets of chromosomes, produces diploid hybrids **C** with 18 chromosomes, of which 9 come from the radish and 9 from the cabbage. At meiosis, pairing of chromosomes is impossible for none are homologous. No viable gametes form, and the hybrid is sterile. If these chromosomes are doubled, meiosis occurs normally. These allotetraploid hybrids **D** are fertile, but they no longer can breed with radish or cabbage. They therefore constitute a new species, which is called *Raphanobrassica.*

POLYPLOIDY AND SPECIATION

Polyploidy has played an important role in speciation, particularly in the origin of many species of angiosperms (flowering plants). A study of the chromosome numbers of closely related species often reveals that these numbers are multiples of certain base numbers; for example, the American species of *Crepis* (plants of the Composite family) have chromosomes numbering 11, 22, 33, 44, and so forth. Species of the genus *Rumex* (subgenus *Lapathum*) have 20, 40, 60, 80, 100, 120, 160, or 200 chromosomes. Such series of chromosome numbers are most likely to arise by repeated polyploidy. Many cultivated plants are polyploids; and some wheats are allohexaploids.

Until the significance of chromosome numbers to breeding problems was generally realized, plant breeders did not know how to interpret the differences in breeding behavior between closely related triploids and tetraploids. Development of methods for determining chromosome numbers has clarified various breeding problems related to polyploidy. An increase in flower size and keeping quality often goes with polyploidy, making polyploids more valuable than diploids.

TRANSLOCATION

It is possible for the number of chromosomes to change without much alteration in the total amount of genetic material. A translocation is the exchange of material between two nonhomologous chromosomes. If a chromosome with genes ABCDEF and another chromosome with genes GHIJKL exchange parts, one of many possible results is the formation of a large chromosome ABCDEGHIJK and a smaller one FL. If FL lacks a centromere, it is likely to become lost in the cytoplasm during a mitosis. The number of chromosomes has diminished by one because two chromosomes have united into one large one with the loss of only a small fragment of genetic material. If the lost fragment contains no essential material, the cells will be able to survive. But if essential genes are lost, the cells will die.

This type of transformation very probably occurred in some species of grasshoppers with short antennae (in the family Acrididae). Most of the species in this family have 12 pairs of rod-shaped chromosomes. The Mexican species, *Aidemona azteca,* has only 11 pairs, one of which is in the form of a V. Similarly, the species *Aleuas viticollis* has only 10 pairs of chromosomes.

Chromosomal abnormalities like these can lead to new species, for hybrid individuals—with one normal monoploid set and the other with a translocated chromosome—are likely to have abnormal meiotic divisions and produce few viable gametes. They are thus genetically isolated from the parent types. In individuals with two identical (homologous) translocated chromosomes, normal pairing occurs in meiosis. These individuals are fertile.

INVERSIONS

Different species do not always have different numbers of chromosomes. A small fragment of a chromosome may break off and then may be returned to its place—but in an inverted position. Inversions like these can lead to meiotic difficulties unless the individual has homologous chromosomes with identical inversions. This, too, results in genetic isolation and perhaps brings about the evolution of new species, especially if many inversions occur. No less than 21 inversions are known in chromosome III of *Drosophila pseudoobscura.*

ROOTS | organs of absorption and support

Roots are the anchors of plant life. Borne by flowering plants, coniferous plants, ferns, and their relatives, they absorb water and dissolved minerals from the soil and hold plants firmly in the soil or on other supports. Mosses, liverworts, algae, and fungi have no roots, although many of them do have simpler structures called rhizoids that perform the same functions.

THE GROWTH OF A ROOT

Every root is differentiated into several regions: root cap, apical meristem, region of elongation, and region of differentiation. Each region contributes to growth in a different way.

The root cap is a small group of cells that cover the tender root tip. Not involved directly in growth, they protect the tip from mechanical damage as it grows downward among rocks, pieces of sand, or other coarse soil particles. Root cap cells continuously become damaged and die, but they are replaced by cells produced in the root tip immediately above.

The tip of the root contains the apical meristem, a region of small embryonic cells that continue to divide as long as the root tip remains alive. By their divisions, these cells produce new cells that contribute to the growth in length of the root.

Above the apical meristem is the region of elongation. Here the new cells produced by the apical meristem elongate, with their long axes parallel to the long axis of the root. Their growth in length is due primarily to absorption of water rather than to the synthesis of new protoplasmic material. The vacuoles of these cells grow very large, and the cytoplasm and the nucleus are pressed against the cell wall. The growth in length of the root, then, is due to the activities of the apical meristem and the region of elongation, the former producing the new cells, the latter accounting for their increase in length.

Above the region of elongation is the region of differentiation. Here the cells have reached their final lengths and begin to differentiate into various types of tissues that perform different functions in the mature root. This region is readily identified by the presence of root hairs that grow only in this part of the root. These hairs—so fine and so numerous that they give this region a fuzzy appearance—absorb most of the water and minerals that enter a plant. The total number of root hairs on all the branch roots of a single plant may reach more than a billion. In many plants the root hairs account for more than half of the surface area of the root and nearly all of its absorbing surface. Like the root tip, the root hairs are very delicate; their presence above the region of elongation assures that they will not be dragged downward through the soil and torn off. As the root grows, however, the oldest root hairs at the top of the root hair zone die, and new ones form below. In this way the root hair zone moves downward always just a little behind the root tip.

A good gardener is careful to dig up a large ball of earth with the roots of any plant he is transplanting. This prevents the root hairs from drying out and dying; before new root hairs could form, the

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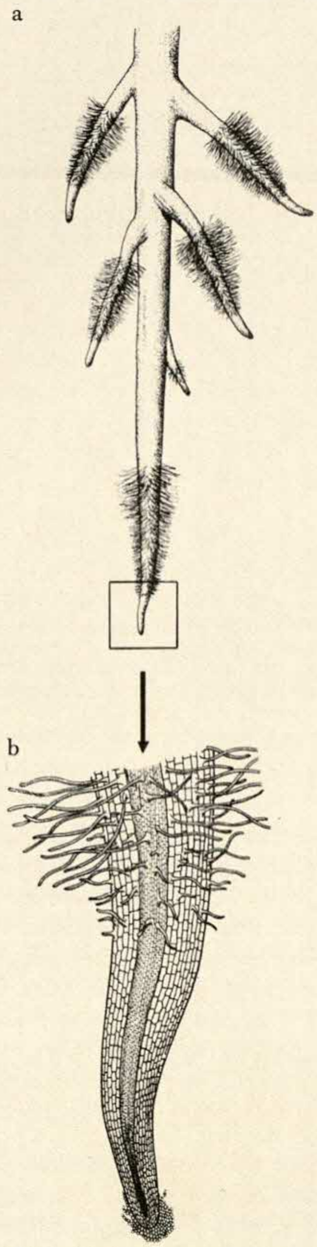

ROOT TIPS—Root hairs grow a short distance from the tip of each branch root (Illustration 1a). Each tip (Illustration 1b) is covered by a root cap.

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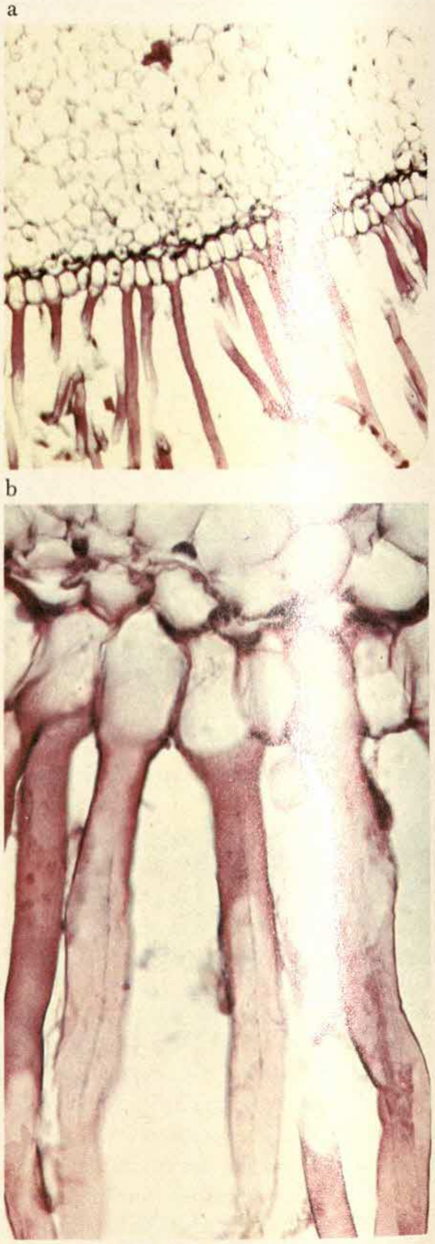


ROOT HAIRS—This photomicrograph (Illustration 2a) of a cross section of a watercress root shows only the external tissues of the root. Cortex occupies the upper part of the photograph, and the epidermis extends across the middle. The root hairs (stained pink) contain cytoplasm, and the nuclei (not visible here) are located in the tips of the root hairs. (100 X)

Illustration 2b, a detail of epidermis and root hairs, shows that root hairs are extensions of epidermal cells and are not separated from them by cell walls. (425 X) plant might very well wilt and die from lack of water. The presence of earth around the roots also protects the root tips, for if they are torn off, no new cells can be formed, and these tips die. If enough root tips die, the entire plant may die.

No growth in length occurs in the mature tissues above the region of differentiation, but in many roots, especially those that live more than one year, growth in width takes place. Here, too, the branch roots form.

The single root that develops from the embryo of a germinating seed is the primary root. Branch roots are roots that develop from other roots, while those that form on primary roots are secondary roots. The branch roots that develop on secondary roots are tertiary roots, and so forth. When the seed germinates, the primary root is the first organ to appear. It grows downward through the soil.

PRIMARY ROOT SYSTEMS AND ADVENTITIOUS ROOT SYSTEMS

A primary root system is one that derives entirely from the primary root; that is, it consists of the primary root and all its branches.

An adventitious root system develops from some part of the plant other than roots; adventitious roots usually grow from stems, but occasionally they may develop from leaves. They augment primary root systems and often replace them. The primary root of a young corn seedling dies early, and all the roots of a mature corn plant are adventitious.

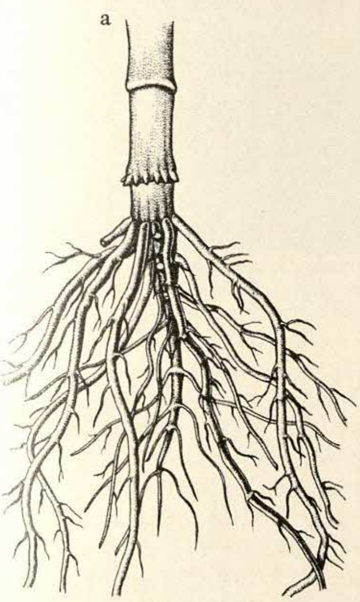
Adventitious roots frequently develop on horizontal stems such as stolons and rhizomes that grow on or in the ground. As the older portions of the stems die, the new branches become separated from each other and form new plants. Because each section has its own roots, it can survive. Strawberries (which have stolons) and ferns (which have rhizomes) can reproduce asexually in this manner. In some species adventitious roots develop only on cuttings that have been separated from the rest of the plant and so have no roots of their own. Adventitious roots may also arise from the leaves of a begonia or African violet planted on the surface of the soil or from geranium stems placed in water.

Some adventitious roots are of special types. Corn plants have whorls of roots—called prop roots—that emerge from the lower nodes of the stem. As their name suggests, these roots act as props that help to support the tall, thin, unbranched corn plant. Mangrove trees and banyan trees have prop roots that grow from the branches of trees and descend to the ground. The aerial roots of ivy are adventitious roots that anchor the plant to trees, fences, or other supports.

3

SEVERAL TYPES OF ROOTS—In a fibrous root system (Illustration 3a) most of the roots are of about the same thickness. A great deal of branching usually occurs, and the roots tend to spread horizontally through the soil. Many grasses, including corn, have diffuse root systems. In a taproot system such as that of dandelion (Illustration 3b), a single root called the primary root is thicker than the secondary roots that branch from it. The primary root of a taproot system often grows deep into the soil. The taproot of a beet is enlarged into a fleshy, food-storing organ (Illustration 3c). The food stored in a hyacinth bulb permits adventitious roots to grow from its stem (Illustration 3d). A celery plant (Illustration 3e) also has a taproot system.

a



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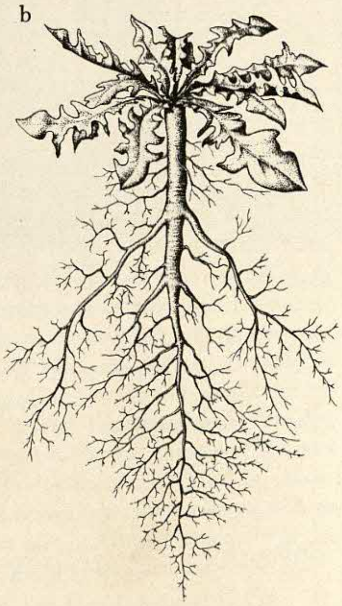

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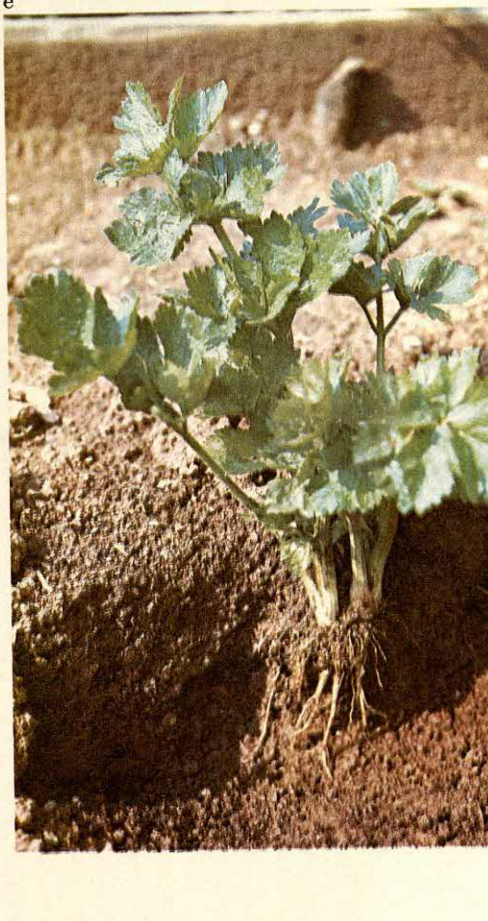

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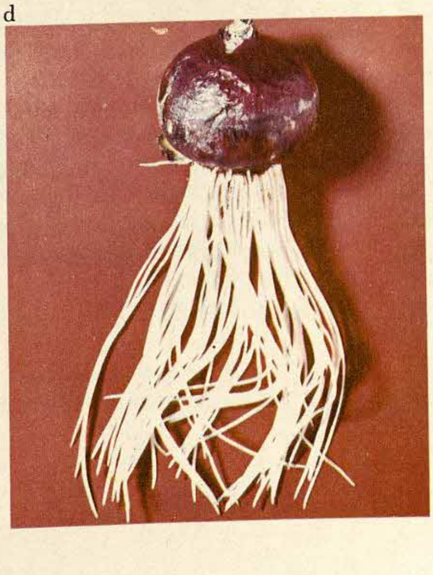
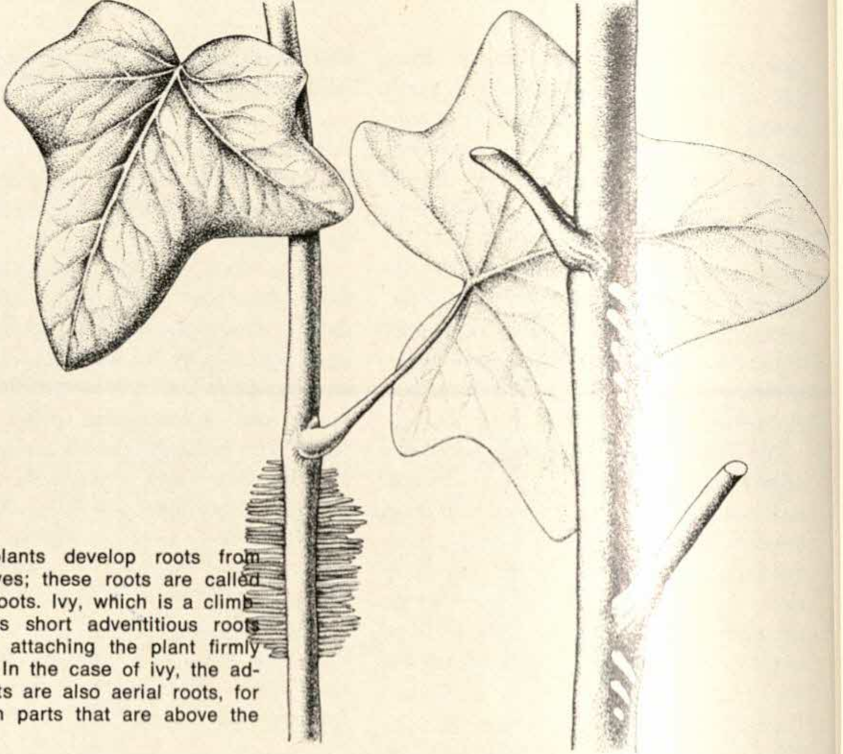




IVY—Many plants develop roots from stems or leaves; these roots are called adventitious roots. Ivy, which is a climbing plant, has short adventitious roots that assist in attaching the plant firmly to a support. In the case of ivy, the adventitious roots are also aerial roots, for they occur on parts that are above the ground.

TAPROOT SYSTEMS AND FIBROUS ROOT SYSTEMS

A taproot system is a primary root system with a well-developed primary root—the taproot—that grows downward in the soil and often reaches great depths. It can be distinguished easily from its branch roots by its greater thickness. Because they penetrate deeply, taproot systems can reach water supplies well below the surface of the soil. Dandelions, beans and alfalfa have taproot systems.

Some taproots are very thick and fleshy and are modified into food-storage organs. Carrots, turnips, beets, and icicle radishes are edible taproots. The sweet potato, which is a swelling of a branch root, is a tuberous root rather than a taproot.

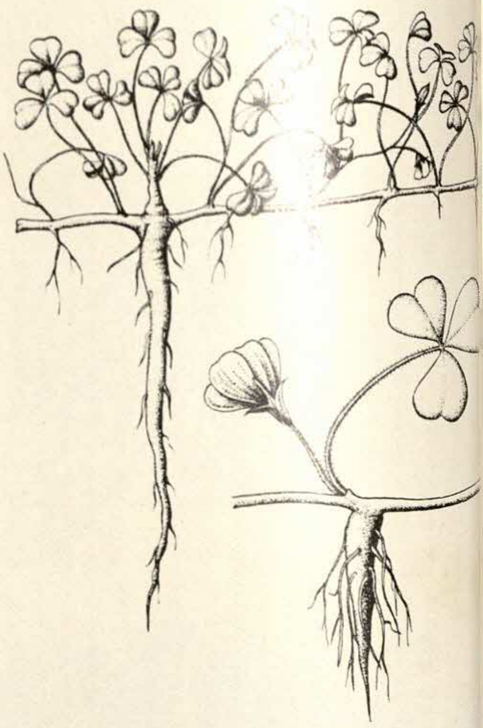
A fibrous root system may be either a primary root system or an adventitious root system. All of the roots in such a system are about the same diameter. If there is a primary root, it may be difficult to distinguish from the others. Fibrous root systems are characteristic of the grasses; these include the cereal grains, such as corn, rice, and wheat. Many of them do not penetrate the soil very deeply, but they spread out in all directions. The fibrous root systems of many cacti obtain water at relatively great distances from the places at which the stem emerges from the ground. 5

CONTRACTILE ROOTS

Contractile roots have the peculiar property of shortening, caused by the shortening of some root cells and the dying of others. Contractile roots are characteristic of many perennial plants that have bulbs (such as lilies) or that have their leaves confined to a rosette at the surface of the ground. The growth of the stem tip in the bulb or the rosette ordinarily would raise the tip higher and higher above the ground each year. This growth is counteracted by the contraction of the roots, and the stem tip remains at its characteristic level just at or below ground level.

REPRODUCTION BY ROOTS

Few plants reproduce by roots alone, for a root without its accompanying stem and leaves usually dies. There are a few exceptions, however. A sweet potato with its lower end placed in an inch or two of water produces stems and leaves that sometimes are enjoyed as ornamental vines in the home. Some weeds, such as dandelion, can sprout from fragments of roots left in the soil.



ADVENTITIOUS ROOTS GROWING FROM STOLONS — Some plants have horizontal stems, called stolons, that grow at or near the surface of the ground. Adventitious roots often develop from their nodes.

THE TERMITES | specialized technicians of the insect world

1

A WINGED TERMITE—The approximately 2,000 known species of termites belong to the order Isoptera (a word of Greek derivation, meaning "equal-winged"). Members of the mating royalty caste have two pairs of similar wings, generally light in color, as in this illustration of a termite on its nest. The wings of some species are unpigmented, dark, or even black.

Termites have survived the long centuries since the dim beginnings of life on Earth because of their perfect social organization. Their genealogy, like that of ants, dates back some 300 million years. During the Permian period, before the families of the birds and mammals had evolved from the great reptiles, the ancestors of the termite first emerged and organized a communal insect society. The discovery of fossil organisms in recent years indicates that, by the time of the Eocene and Oligocene periods, these insects had survived cataclysmic changes in the Earth's environment and had already formed the physical and social characteristics of the termite family as it exists today.

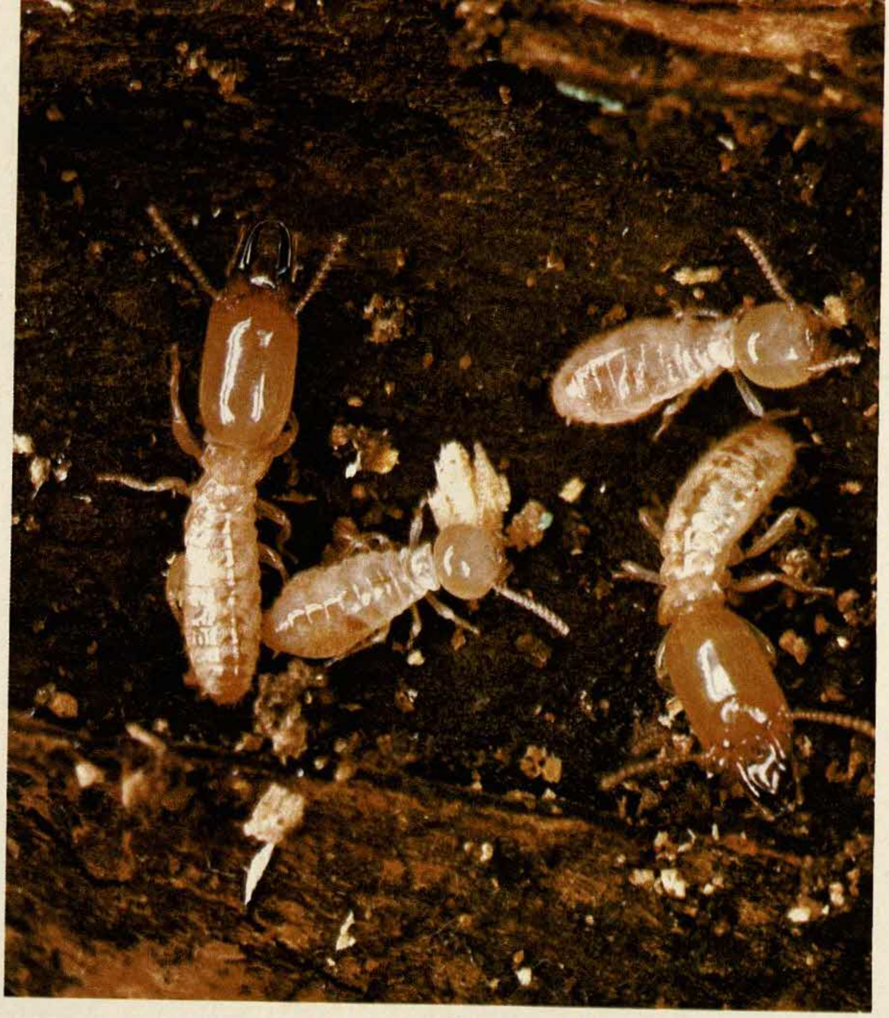
Through the centuries termites have frequently been confused with ants, perhaps because of some of their habits and characteristics—size, social organization, and nest building. Most of the approximately 2,000 known species of termites are whitish in color, a characteristic that has led to the misnomer "white ants." However, termites (the name was derived from the Greek word *termes*, meaning "wood-boring worm") are not related to the ant family, but are members of the order Isoptera (Pterygota), a very primitive family of insects similar to the cockroach. Although they are master builders, termites have very few natural defenses. They do not have a hard and chitinous skeleton, and their soft bodies are defenseless against lesions and climatic variations. Only a few members of a termite colony have visual organs and wings, and these members are totally lacking in defense mechanisms.

CASTES AND CHARACTERISTICS

Like ants, most termites are ground-nesting insects. A termite colony, or nest, is populated by four distinct adult castes—the royalty, the nobility, the soldiers, and the workers. The physical characteristics of these castes vary markedly. The royalty consists of the colony's ruling winged king and queen, and young kings and queens who, on reaching maturity, fly from the nest to establish new colonies. The queens are the largest members of the termite colonies, at times becoming giants in the insect world. An old queen (some live as long as ten years) may be 15 cm (about 6 in.) long and as big around as a small sausage. Because of her size, the mature queen cannot move. She depends on the workers to feed and clean her and to carry away the eggs she produces in a seemingly endless flow. The king, after the first mating with the queen, remains constantly at her side.

The nobility of a termite colony consists of fertile, wingless adults, who assume the responsibility of reproduction

2



WORKERS AND SOLDIERS—Workers of this species (*Reticulitermes lucifugus*) have a pale tegument and poorly developed mouthparts, and are blind. The soldiers also are blind but can be recognized easily by their much larger size. They have harder heads than workers, and strong, scissorlike mandibles.

if the king or queen dies. The vast majority of a colony's population—the workers and the soldiers—are wingless, blind, and much smaller than the royalty and nobility. Although the worker caste consists of males and females, both are sterile. Their responsibilities, in the strict social system of termites, are to protect the colony from insect invaders, to supply it with food, to care for the young, and to build the nest and keep it in orderly, livable condition.

The mating of young kings and queens follows a ritualistic, unvarying pattern. For the first and only time in their lives, the newly matured members of the royalty emerge from their colony in pairs when they are about a year old. In this once-a-year mating of the young kings and queens, many fall victim to the elements, birds, or predatory insects. Those who survive start new colonies nearby. Once a new colony has been established, the royal couple sheds its wings. Within a short time, the queen begins producing eggs—as many as 5,000 per day.

Worker "nurses" immediately take custody of the eggs. They coat the eggs with saliva, to guard them against mold, and then carry them to a nursery in the nest, where they are kept warm with blankets of fermenting vegetation until they hatch.

THE COLONY

A long-established termite colony may contain from about 700 to as many as 3 million individuals. Because of its exceedingly slow cycle of development, a termite colony requires many years to reach a full density of population. For example, a year after the nest is founded, a colony of *Calotermes flavicollis*—a

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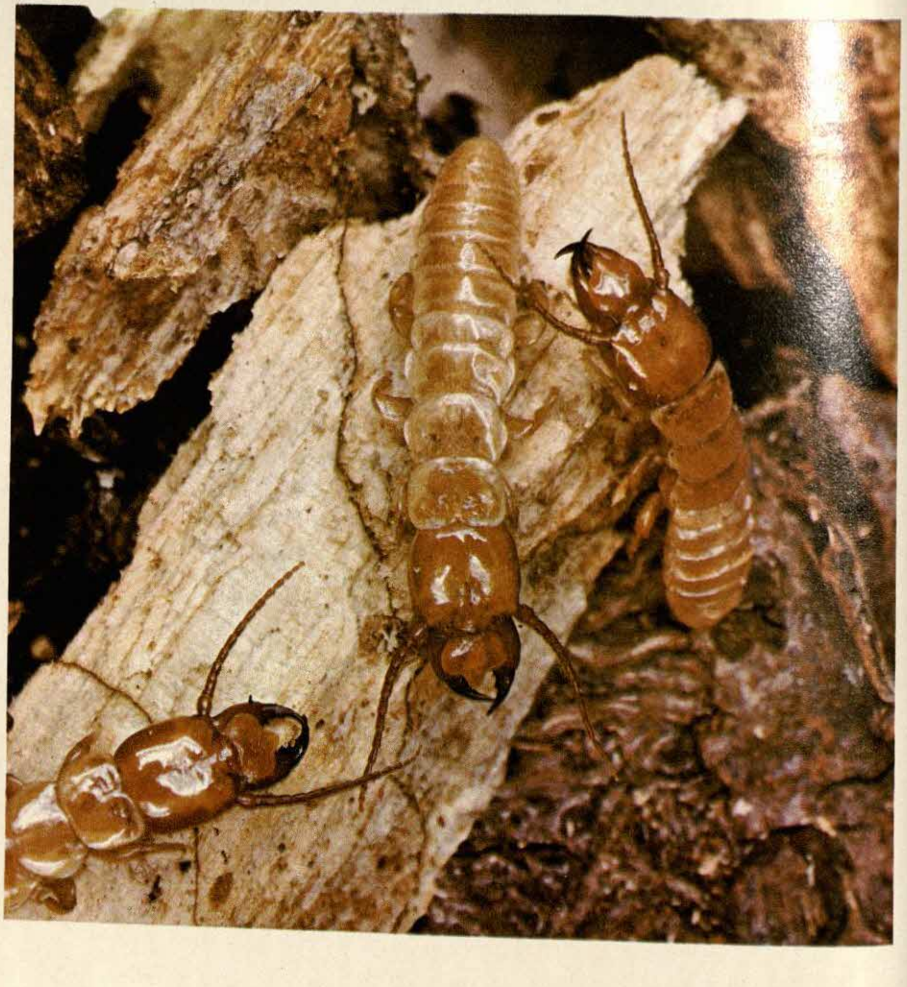

SOLDIERS—Visible in this illustration of *Psammotermes hybostoma* are the strong head and the mouthparts that are specialized for defense of the nest. Soldiers are rarely capable of nourishing themselves and are fed by the workers with material that already has been digested and regurgitated in a manner similar to that utilized by ants.

wood-borer species widespread in Italy—consists of about 12 individuals, including a soldier termite. After two years, the colony consists of fewer than 40 individuals, and only after five years does the colony attain its maximum population of about 700. Other species of termites, whose colonies reach a maximum population of a few million, require much longer periods of time for full development of the colony.

Although the vast insect world contains many families of nest builders, none build their nests so large or engineer them so skillfully as do termites. They cannot survive in the outside world, where exposure to light and air would kill them within a few hours. Termites—except for the brief mating flights of the kings and queens—must live out their existence in dark, closed places where they maintain, by various instinctive means, optimum and constant conditions of temperature and humidity.

TERMITES AS ENGINEERS

Most of the 56 species of termites found in the United States are ground nesters, living in complex nests that are partially or wholly underground. Certain species build nests among the branches of trees, while others dig networks of tunnels and chambers in tree trunks. In Africa, South America, and Australia, some species build nests completely above ground. These moundlike nests, constructed of saliva-soaked soil particles, are as hard as concrete. Some termite mounds, hundreds of years old, are exceptionally large—as much as 20 feet tall and 40 feet wide.

Among the ground-nesting termites, the task of building the nest is assigned to the workers, who—like the mound builders—use saliva-soaked soil particles to form the concrete-hard walls of the colony's underground chambers and passageways. The construction of a nest is amazingly rapid. If a nest is destroyed, it may be rebuilt in little more than 48 hours.

Both inside and out, termite nests have architectural characteristics that differ from species to species. In all cases, however, a large chamber—the royal residence—is located in the central portion of the nest. Here, the queen lives with her king, waited on, pampered, and protected by the multitude of workers and soldiers, who guard the chambers and entrances of the nest with their scissorlike jaws. Whether above or below ground, the exterior of the nest is constructed with a sloping roof and systems of gutters that guard against flooding.

ADULTS AND LARVAE—Termites undergo an incomplete metamorphosis. All larval stages are constituted of lively and active individuals. At the time of the final molt, however, certain species (such as *Termes bellicosus*, shown) enter into brief periods of inactivity, during which the larvae remain completely immobile until they have attained their adult form.

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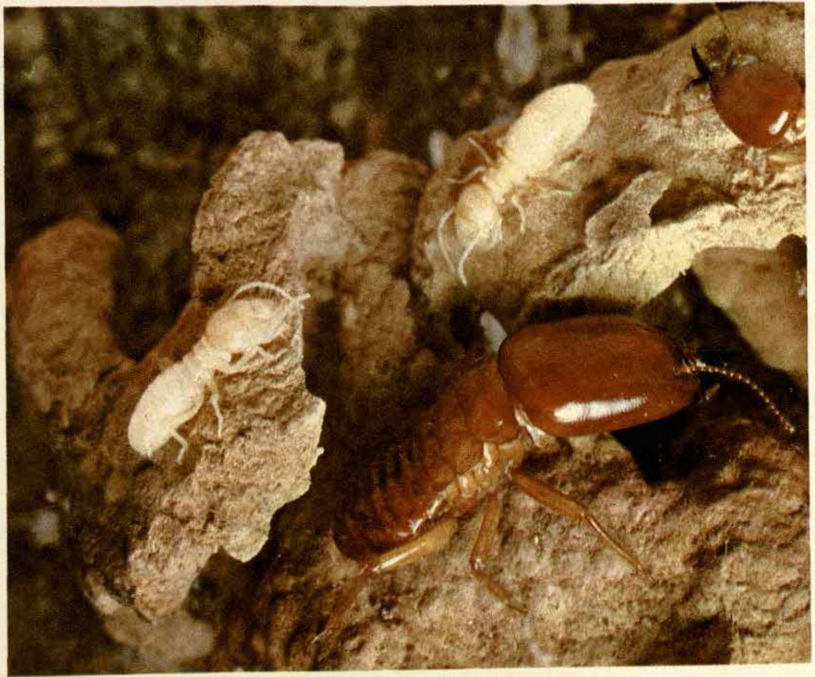

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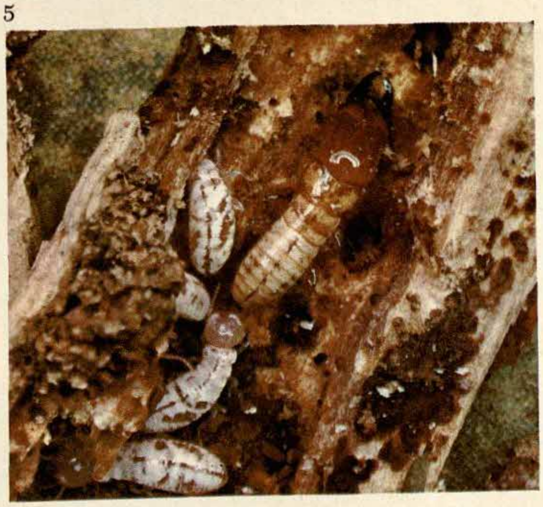

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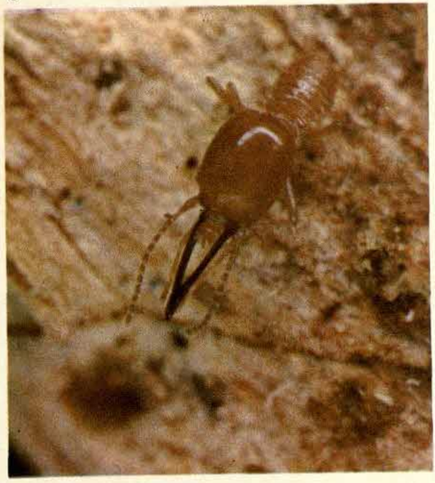
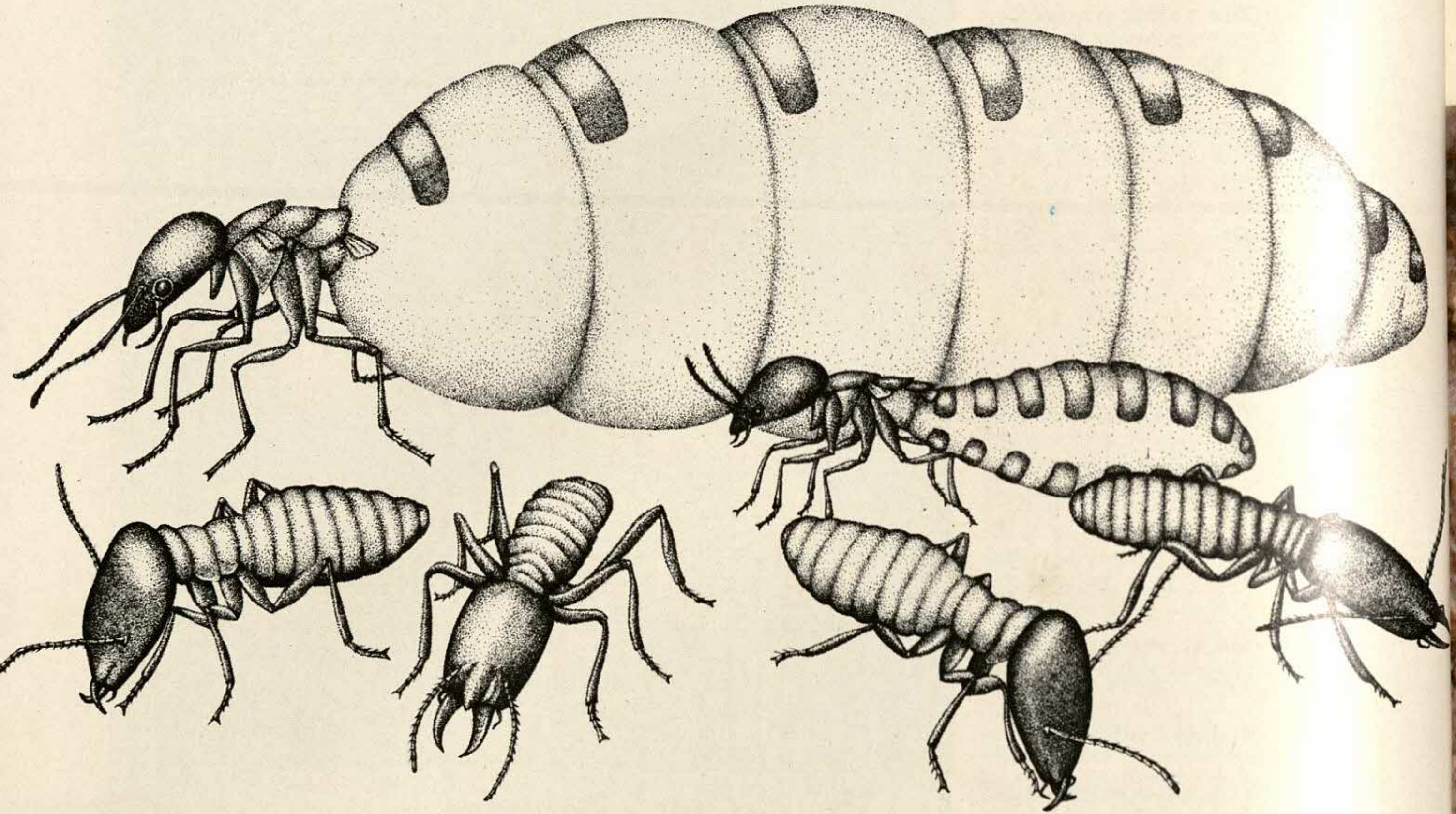


NEST IN A TREE TRUNK—The species *Calotermes flavicollis* builds its nest in the wood of old or broken trees. In this gallery workers and soldiers are visible.

PRORHINOTERMES BELLICOSUS—This species is native to the tropical zones of America and to Polynesia. The soldiers, one of which is shown here, have a special frontal gland that emits a sticky, irritating liquid that the insect uses to defend itself from its enemies.

The most extraordinary characteristic of termite engineering—a feature common to all species—is a system of construction that provides the colony with ventilation and an amazingly constant range of temperature and humidity. A medium-sized termite colony requires about 1,500 l (about 530 cu ft) of air



THE ROYAL COUPLE AND ITS COURT—The queen exhibits the typical abdominal hypertrophy and abnormal swelling of the abdomen, which is full of eggs. The queen may be many times larger than other members of the colony. With her are the king and two soldiers, which have strong mandibles to protect her, and two workers, which feed her and carry away her eggs. Because of her great size, she cannot move. The queen is exceptionally fertile, laying as many as 36,000 eggs in one day. When fertility ends, she is left to starve.

each day to provide adequate oxygen for the inhabitants of the nest. If this oxygen were provided by direct air intake, the temperature and humidity of the nest would be altered far beyond the termites' survival point. Termites have resolved this problem by creating damp cellars in the nest. Outside air enters these cellars through thin-walled conduits built on the surface of the nest. From the damp cellars, the conduits extend to a hall, or attic, at the topmost part of the nest, to which the air, warmed by the bodies of the insects, rises. Thus, by means of a simple physical principle, this termite engineering system creates a circulation of air that is regulated continually by the colony's workers. As the need arises, workers open and close the conduit tubes with such precision that while a constant exchange of air is maintained within the nest, only minimal variations of temperature and humidity occur.

DIET

The intense activity of the individuals in a termite nest accounts for the great quantity of food they consume to rebuild the energy they expend. For example, when the queen has attained her maximum size, she deposits about 36,000 eggs every 24 hours, or about 13 million eggs a year. This annual volume of eggs—about 150 times the queen's weight—produces a population explosion which makes the housekeeping and feeding of a termite colony an endless, monumental task.

The basic food of all termites is wood, particularly dead wood. However, some species are omnivorous, while others eat humus. Some mix bits of wood with saliva, forming a spongy substance on which they cultivate certain species of fungi to supplement their diets. Many termite colonies also keep "herds" of captive insects (of the Coleoptera and Diptera families) as a source of food. These insect herds supply sugary discharges that are a favorite termite food. To provide a great part of their protein requirement, all species of termites devour the corpses of termites that have died within the nest.

A UNIQUE DIGESTIVE SYSTEM

The wood-eating capability of termites makes them both a unique life form and one of mankind's most destructive insect pests. Termites share their food source with no other insect. Their huge and constant appetite is fed, in large measure, by trees, plant material in the soil, house timbers, fence and telephone poles, furniture, and other wood products of man and nature. Termites cannot digest cellulose without help. To do so, they rely on a symbiotic relationship with protozoans—microscopic, one-celled creatures that both workers and soldiers harbor in their intestines. When the wood chewed into

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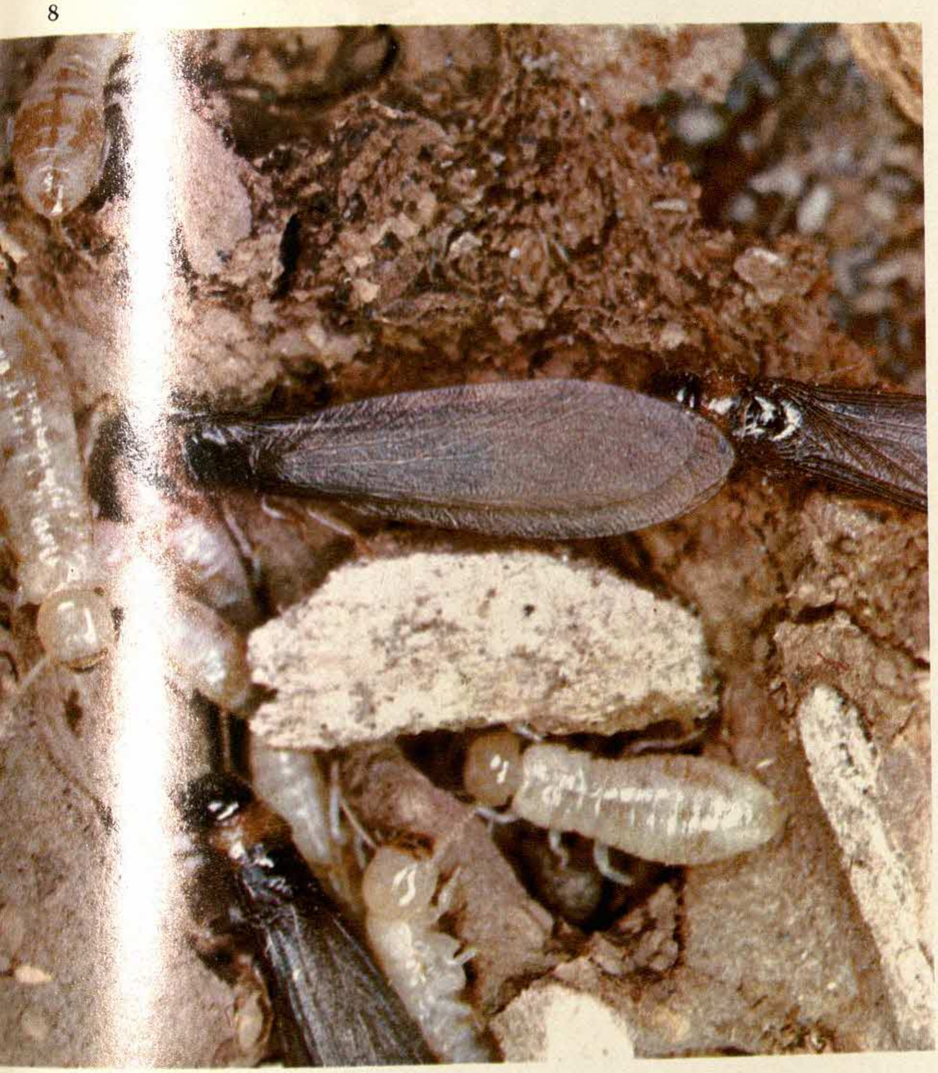

CALOTERMES FLAVICOLLIS—The dark-colored, winged individuals are fertile males and females of the royalty caste, while the pale, wingless insects are sterile workers and soldiers (Illustration 8).

REPAIRING DAMAGE TO THE NEST—The soldiers and workers (at the center) cluster around a damaged zone in the nest (Illustration 9).

PREPARATION OF THE NUPTIAL CHAMBER—After the young, winged kings and queens swarm from the old nest, the new royal couples are formed. Once the so-called mating flight has taken place and they have lost their wings, each couple excavates the first cell of a new nest, in a place chosen by the queen. In this new nest mating occurs and eggs are deposited. Only after many years does the new termite colony reach its maximum density of population (Illustration 10).

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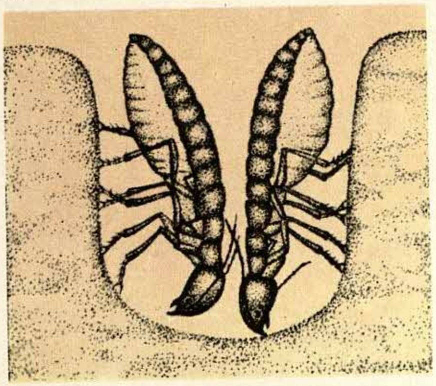

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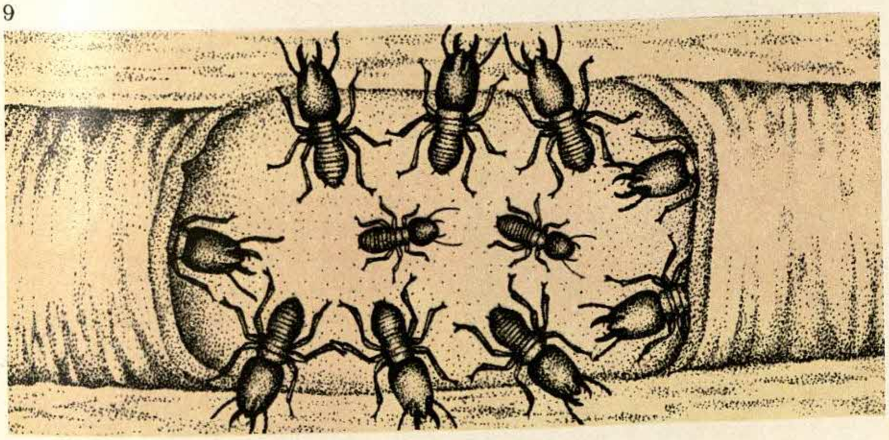

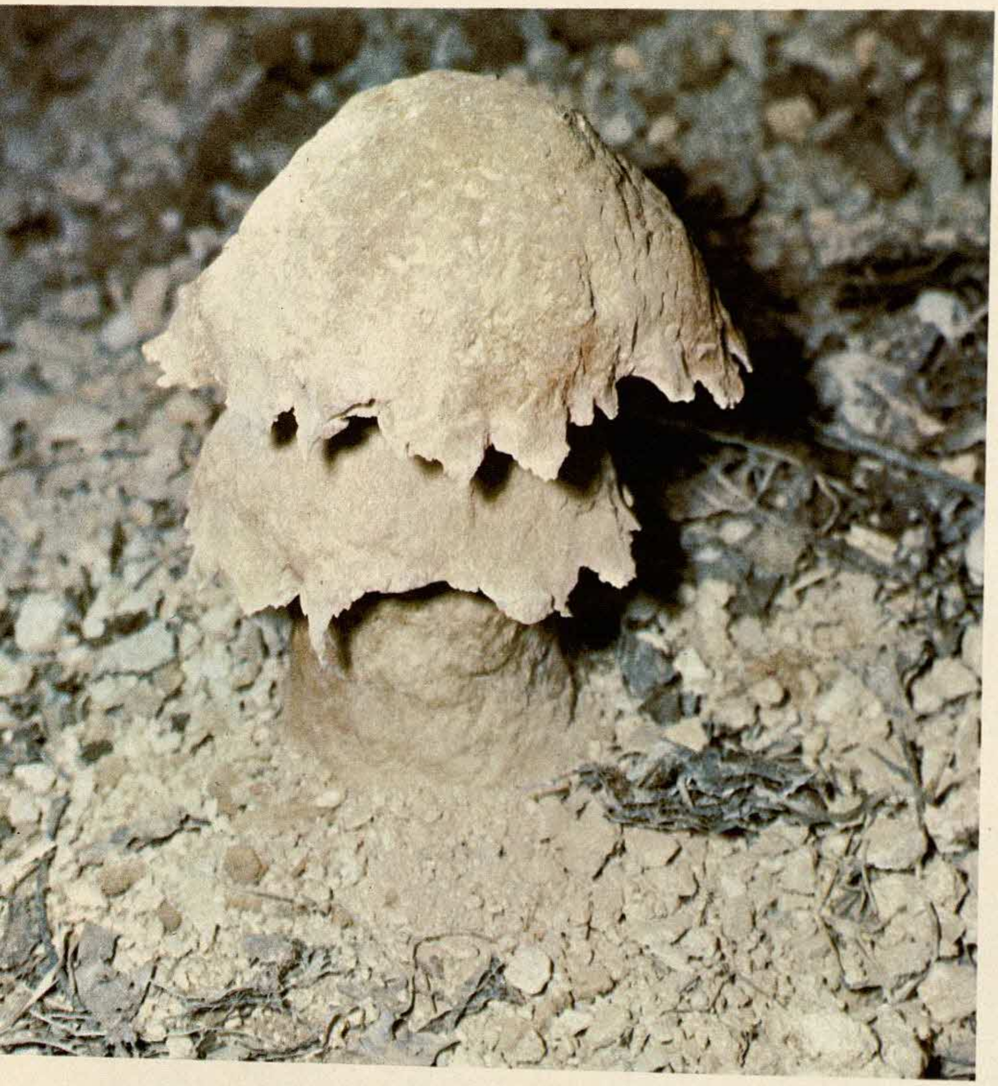

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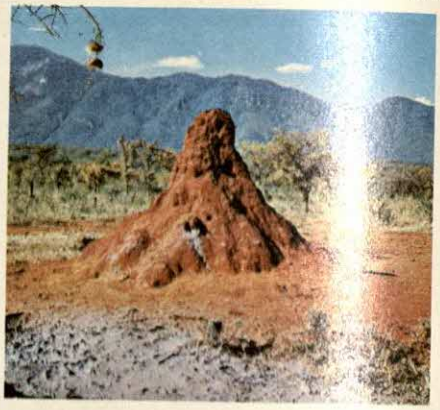

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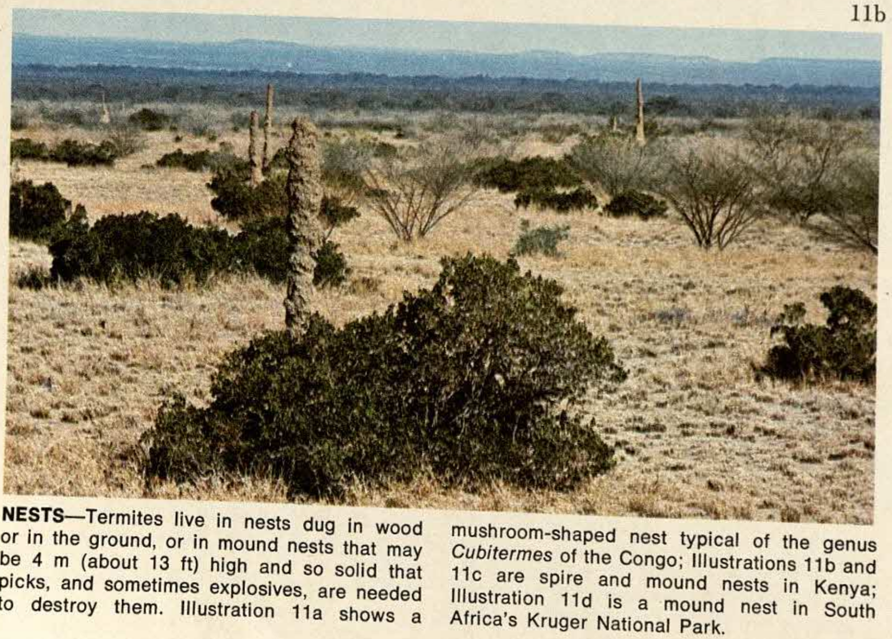

11b

NESTS—Termites live in nests dug in wood or in the ground, or in mound nests that may be 4 m (about 13 ft) high and so solid that picks, and sometimes explosives, are needed to destroy them. Illustration 11a shows a mushroom-shaped nest typical of the genus *Cubitermes* of the Congo; Illustrations 11b and 11c are spire and mound nests in Kenya; Illustration 11d is a mound nest in South Africa's Kruger National Park.

a pulpy mass by a worker reaches the upper intestinal tract, it is ground up in special valves and passed into a sac formed by the lower intestinal tract. Here the wood is attacked by millions of protozoans, whose enzymes break it down into substances easily assimilated by their host.

Termites are born without the protozoans that provide the vital cellulose-digesting function. Thus, young termites would die of starvation if the adult workers did not intervene. The workers regurgitate digested food—and protozoans along with it—into the mouths of the young termites. The protozoans then settle down in the intestines of their new hosts, ensuring that the life cycle of the next generation of termites will be maintained by nature's most unique and cooperative digestive system.

THE ANTS | the superefficient animal society

WORKER ANT ON A RIPE FIG—Ants belong to the immense order of the Hymenoptera and comprise the family Formicidae. They probably appeared on the Earth during the Jurassic period. Ants live in colonies that are very complex and specialized. In a colony there are sterile females, called workers; fertile females, or queens; and, at certain times of year, winged males who live only until shortly after mating. The size of ants varies considerably from one species to another.

Ants are the most socially advanced and most numerous of any insects that exist on Earth. They live and work in groups known as colonies in a highly organized society and are, in certain respects, similar to people. Found in all parts of the world except the extremely cold polar regions, ants make and store food, feed and care for their young, guard their colonies, and fight wars. They raise "livestock" and even communicate with each other. Termites and bees also live in complex colonies, building nests that are more complicated and more perfect than those of ants; but the social organization and specialized duties of ants cannot be equaled by any other insect.

The more than 5,000 species of ants that comprise the family Formicidae are of very ancient origin. Ants first appeared on the Earth during the Jurassic, or perhaps the Permian, period. The social organization of ants into tribes occurred before that of the bees and wasps, and the subdivision of ants into castes had already taken place 30 to 40 million years ago.

Unlike bees and wasps, all species of ants have a social organization. A colony may survive for extremely long periods (on the average, the workers live seven years and the queens up to 15 years).

Ants can be classified, generically, as aculeate, social Hymenoptera. They are distinguished anatomically by a very small metathorax (the posterior segment

2a

2b

3

SECTION OF A NEST OF RED ANTS—Ants' nests are built in ways that vary according to the species, and they generally are constructed without a precise geometric plan. On the inside, in large or small chambers connected by tunnels, workers and larvae are shown in various stages of development (Illustration 2a). The cocoons containing larvae in the final stage of metamorphosis are shown in Illustration 2b.

ANTS TRANSPORTING LARVAE—Special care is given to ant eggs and larvae by workers, who continuously monitor the various stages of their development (Illustration 3).

LARVAE IN VARIOUS STAGES OF DEVELOPMENT—When it emerges from the egg, the larva resembles a tiny, legless white worm. In most species of ants, the larval stage is followed by the pupal stage, where the ant is formed but still enclosed in the cocoon. In

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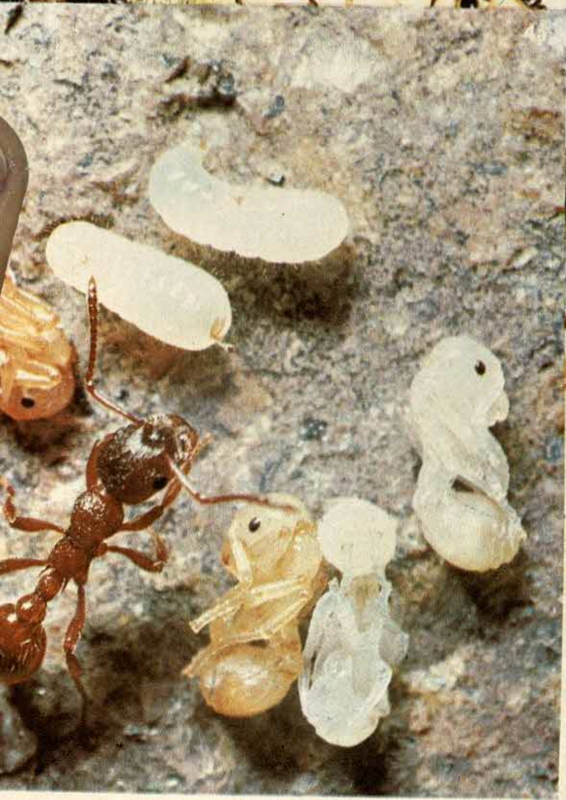
of the thorax), which contains the two glands that are characteristic of the species; by the modifications of the first two or three abdominal segments; and by their jointed antennae, which are composed of four to 13 segments.

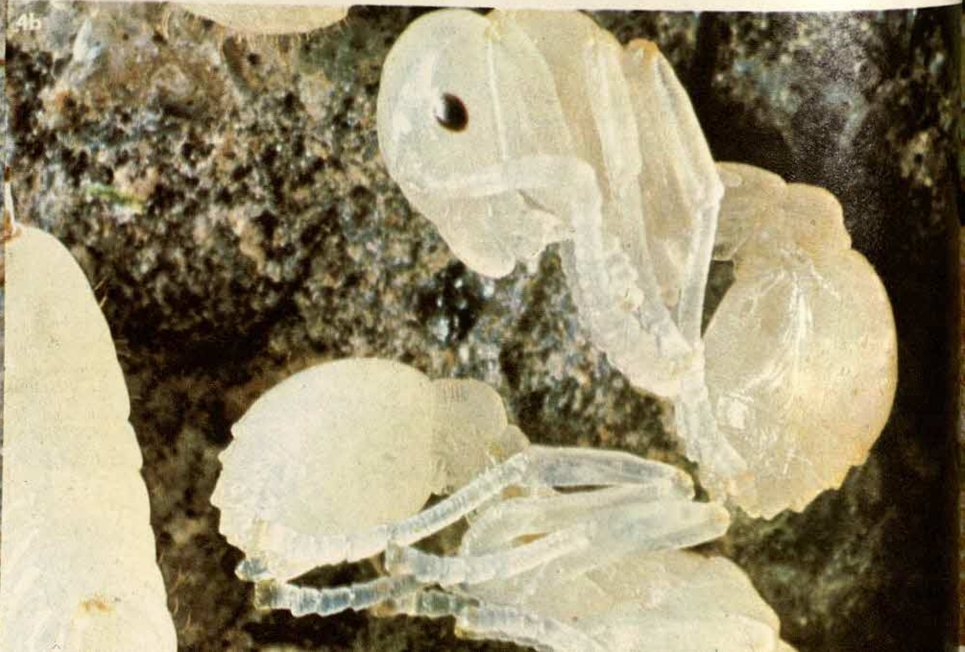
There are two types of adults: fertile females, or queens (there may be more than one), and a much larger number of wingless, sterile females called workers that live in their nests during all seasons. At certain times of the year these two types are joined by winged males, who live only long enough to fertilize the queens. After fertilization, some of the queens leave the nest to form new colonies.

The size of ants is extremely varied, according to the species, and ranges in length from the 0.8 mm (about 0.03 in.) of the genus *Solenopsis* of the tropics to the more than 4 cm (about 1.6 in.) of the females of the genus *Anomma*.

The form of the ant is essentially similar in both sterile and sexed individuals, but each caste is identified by some individual characteristics. Queens, the largest ants, lose their wings after fertilization. Their heads, although much bigger than those of the workers, are similar to them



4a



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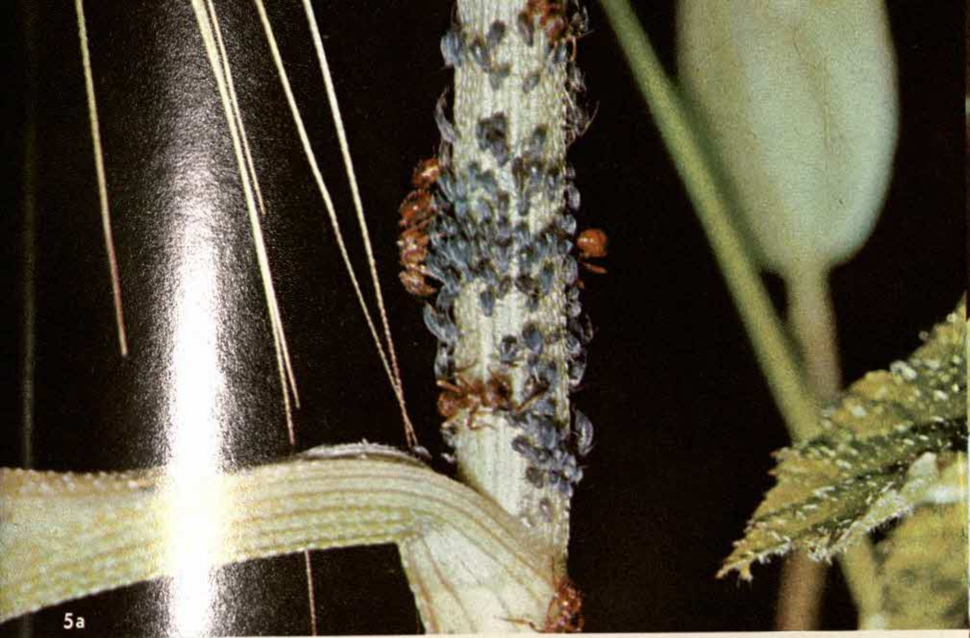

5a

5b

some cases, the nymphs are naked (Illustration 4a and 4b). In Illustration 4b the characteristic parts of the adult are visible in the nymph, which remains motionless for a certain time until, with the help of the worker ants, it frees itself from the cocoon.

ANTS AND APHIDS—Aphids secrete an inebriating sugary substance that is particularly prized by ants. Certain species of aphids are raised in ants' nests for the purpose of providing this substance as food for the colony.

ANT NESTS—These nests (Illustration 6a and 6b) attached to tree trunks are typical of ants found in Brazil.

A SIAMESE ANT AND A WINGED ANT—In Illustration 7a the various parts of the ant's body are clearly distinguishable: head, thorax, metathorax, and abdomen. The winged form of ant as it appears in the summer is shown in Illustration 7b.

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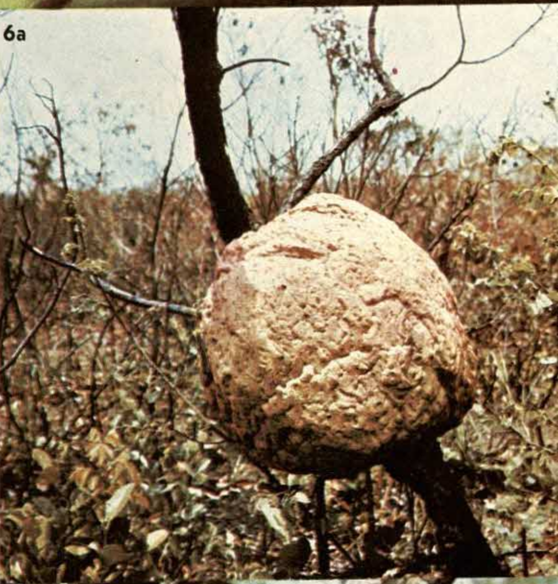
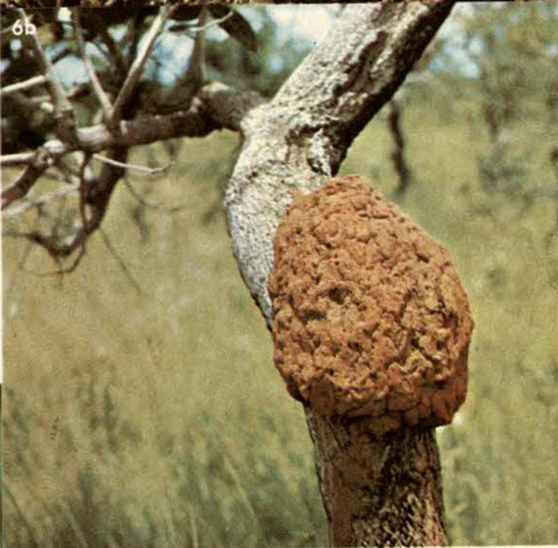
in appearance. The workers, all sterile females, are always wingless and have fully developed heads with mandibles that may be extremely large. The lifespan of the workers is shorter than that of the queens. Males always have wings and small heads, with mouthparts so incomplete as to make feeding themselves impossible. They are nourished directly by the workers throughout their brief lives, which are never longer than 90 days.

Ants have a nervous organ that functions like a brain, and they also have several sensory receptors located all over their bodies. By means of their photosensory organs (compound eyes or ocelli), ants not only see directly but also orient themselves as if they were furnished with a compass. Even more important are the olfactory receptors, with which the ant finds its way back to the nest, orients itself in the dark maze of the nest, and recognizes food, the members of its colony, and intruders, even in total darkness. Certain ants attack their own kind if deprived of the sense of smell by amputation of their antennae. Other important sensory organs are the auditory receptors.



6a



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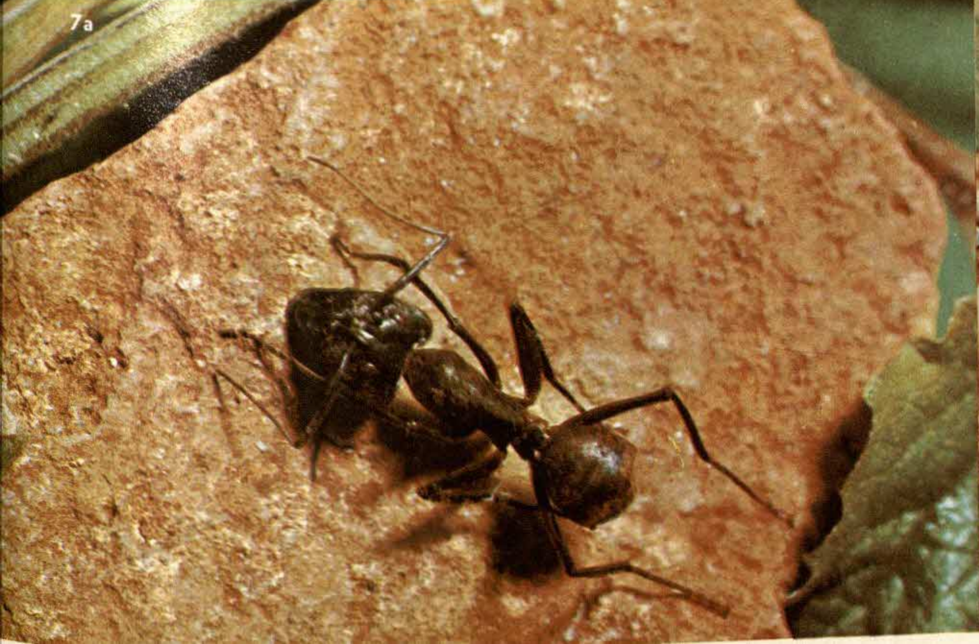
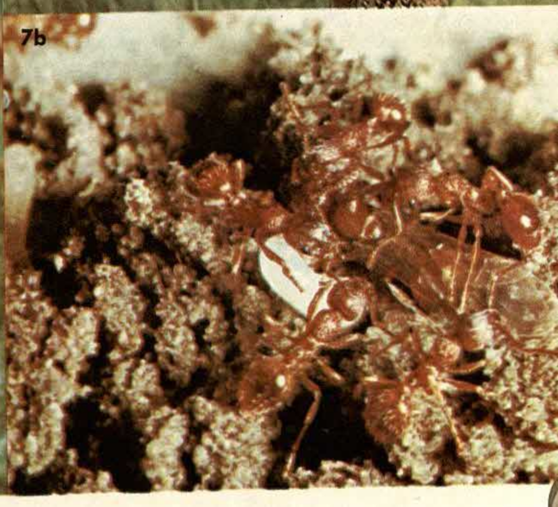


7a



7b

THE COLONY AND THE NEST

The formation of a colony of ants begins with fertilization. After mating, the queen finds or digs a hole in the ground. She walls up the entrance and immediately lays some eggs. For almost a year she does not see daylight again. She herself cares for the first larvae, feeding them, and herself as well, with others of her own larvae. When the new workers are ready to leave the nest, they go in search of food. They also care for the queen, the eggs, and the larvae. They enlarge the nest to make room for the growing colony; and they defend it from its enemies.

An ant colony is usually inhabited by a single species. Sometimes, however, queens are not capable of raising their young. After mating, these queens enter the nests of ants of other species, where, if they are not forced out or killed, they lay eggs and entrust the care of their larvae to the host ants. In other cases, after the workers are born, the intruding queen abandons the host nest, taking her own colony with her to found a new one. In still other instances, she may kill the host queen and slowly substitute ants of her own species for those of the host species.

In certain species where workers are incapable of carrying out all of their duties, a form of slavery exists. These ants raid the nests of other species of ants, carrying off eggs, larvae, and pupae. Once grown to adulthood, the enslaved ants are forced to perform all types of work for their masters.

Depending on the size of the colony, there may be one or more queens in a single nest. They occupy large cells at the safest point in the depths of the nest, where conditions of humidity and climate are optimal and constant. A large band of workers gathers around them, defending them in case of danger.

8

JANITOR ANT AT THE OPENING OF ITS NEST—This illustration shows the anterior part of the ant's head, with the antennae, typically jointed and having four to 13 segments. The mandibles, especially in the predatory species, are strong and well developed.

ANT CARRYING A SEED—Seeds, especially wheat, rye, and barley, are foods preferred by many species of ants, who store the grain in underground warehouses, for use during the winter. The seed being carried is much larger than the ant itself (Illustration 9).

LABOR IS THE BASIS OF THE ANTS' SOCIETY

The tasks performed by the workers, whether in the nest or outside it, may be extremely complex and are not limited to instinctive functions. It has been determined that when ants are faced with the unexpected they modify their behavior, adapting it to the new circumstances. The most important duty of the workers is to search for and to prepare food, a task which they perform with tireless industry, frequently carrying loads many times heavier than themselves. Ants are usually omnivorous, but some species are exclusively vegetarian or carnivorous; others prefer sweet substances or choose particular seeds or fungi as their basic food. The Messor ants, for example, gather the seeds of plants belonging to the grass family and have a special fondness for wheat, rye, and barley. They store this grain in large underground

9

10

ANTS PREPARING FOR THE MATING FLIGHT—At certain times of year the male ants appear. They are winged and smaller than the female; they die after mating. As the queen rises in flight, she is followed by a cloud of males, one or more of whom fertilizes her. The queen then sheds her wings and withdraws to a sheltered nook where she lays her first eggs—the beginning of a new ant colony. For almost a year the queen does not see daylight. She devotes herself to the care of her larvae until the first workers develop.

warehouses, where various procedures prevent germination.

The organization of the food supply has reached maximum perfection in the ant world, where true agriculture and animal husbandry are practiced. Some species, known as leaf-cutting ants, harvest pieces of fresh leaves, cutting them off the trees and carrying them to large hollows in the earth. Here, the ants chew and work the leaves to make a fertilizer on which they sow the mycelia (masses of filaments known as hyphae) of certain fungi, which, when grown, form "meadows" to which developing larvae are brought to feed. The air in these meadow greenhouses is maintained at a humidity level of 60 percent and a constant temperature of 25° C (77° F).

Other species devote themselves to the raising of livestock, particularly of certain aphids, which they keep in herds of 30 to 100 individuals. The ants move these herds from one feeding ground to another, defending them, and taking them along on the migrations of the colony. From these insect "cows," ants get a kind of nourishing, milky sugar.

Some species of ants have attained a high level of food specialization. In the case of the so-called honey ant, certain members of the colony are used as food storage reservoirs. They live hanging from the ceilings of the largest tunnels, continuously taking the honey brought from the outside world by the worker ants and accumulating it in their abdomens, which swell to the size of a pea. These living honey barrels constitute food reservoirs for those periods during which the climate imposes a cloistered, exclusively subterranean life on the colony. The phenomenon of trophallaxis, the mouth-to-mouth exchange of food between adults and between adults and larvae, exists in ant colonies.

PARASITISM AND SYMBIOSIS

Along with the fertile queens, sterile female workers, and males in an ant colony, there are other ant forms, which cannot be classified according to caste or sex. These are abnormal beings destined to a short life. Colonies may also contain various insect guests. Some of these feed on ants and are, therefore, attacked. Others feed on wastes and are accepted as tenants, since they serve to keep the nest clean. Still others are sought out by the ants, who defend and nourish them so as to make use of their particular secretions or even their flesh. A total of about 3,000 species of insect guests have been identified in ant colonies.

According to their habits, ants are divided into several groups that include numerous species. Some of these groups are carpenter ants, amazon ants, carnivorous ants, nomad ants, seamstress ants, warrior ants, robber ants, army ants, and slave-owning ants.

THE LIFE OF THE HONEYBEE

APIS MELLIFICA—The honeybee belongs to the order Hymenoptera, family Apidae, and genus *Apis*. Among the many varieties (races or breeds) commonly raised are *ligustica,*

Since the days of the ancient Egyptians, the honeybee has been a friend of man. Not only does it produce the honey that man uses and enjoys, but it performs the very important function of pollination. In addition, honeybees have fascinated laymen and scientists alike because of their intriguing, intricate, and well-organized social life.

While the honeybee is the best known of the species, over 3,000 different types of bees exist in North America; and only 52 of these live in colonies. The honeybee (*Apis mellifica*) belongs to the order Hymenoptera, suborder Apoidea, and family Apidae. A number of subspecies (races or breeds) exist such as *ligustica, carnica, sicula,* and *cypria.*

All North American honeybees have been introduced, cultivated, and naturalized; hence, in a sense they are domesticated animals. They live in tightly organized colonies or societies consisting of 30,000 to 60,000 individuals divided into two castes: the reproductive males and females, and the sterile workers. Each active hive or colony has only one reproductive female, the queen, and about 100 males or drones. The rest of the colony is made up of thousands of sterile females with imperfectly developed sex organs. Only the queen and drones, therefore, are capable of reproduction. The queen and the workers have a complicated sting apparatus at the end of the abdomen; the drones have no stings. The workers do all the work of the hive—collecting food, feeding the young, building, repairing and guarding the hive, and in general looking after all the housekeeping jobs of the colony.

LIFE CYCLE OF THE HONEYBEE

The life of the bee colony centers around the queen. She is the largest individual in the hive, and has a long, pointed abdomen not completely covered by her short wings. A virgin queen leaves the hive for her nuptial flight when, in her adult life, she is about five or seven days old. She is followed by a number of drones. Mating occurs during flight and results in the death of the successful drone. The queen returns to the hive and does not mate again, nor does she leave the hive unless the colony becomes overcrowded and swarming occurs. The millions of sperms received during the nuptial flight are stored in a receptacle in the queen's abdomen and will remain alive during her lifetime.

As soon as she returns from the nuptial flight, the queen begins to lay eggs, up to 3,000 a day. Each time an egg is deposited her abdomen dips into an empty honeycomb cell, a process that continues while she is being fed and groomed by the workers—and even while she is asleep. Her sole function, then, is reproduction; indeed, the future of the colony depends on her continuing ability to lay eggs. During her entire lifetime (four or five years) she will eat only royal jelly, a substance rich in certain vitamins and produced by the hypopharyngeal glands of the workers. This jelly is mixed with pollen and honey, and is fed to her by the workers.

Most of the eggs that the queen lays are fertilized as they pass by the sperm receptacle in her genital canal. These fertilized eggs may become either workers or queens, depending on the food and

carnica, *sicula*, and *cypria*. The honeybee was introduced in North America and cultivated.

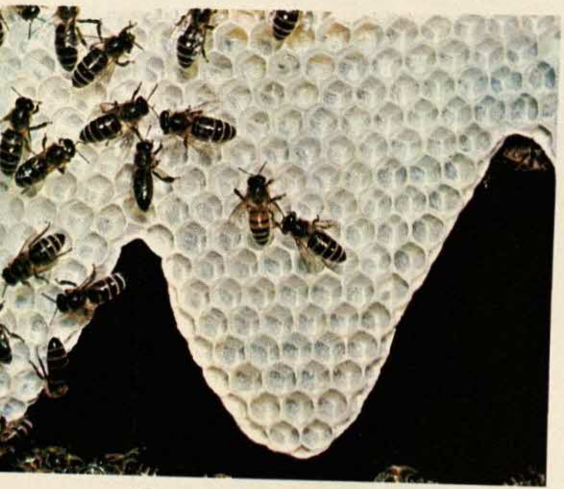
BEE ON A HONEYCOMB—The honeycomb, composed of a large number of cells, is the home of a colony of bees. Each honeycomb cell is a perfect hexagon.

care that they receive. The eggs hatch after three days, forming legless, maggotlike larvae. If they are to become workers, nurse workers feed them pollen and honey kneaded into a mass called "beebread." The larvae consume from 1,000 to 1,300 meals a day, quintupling their weight in the first 24 hours. Six days after hatching, each larva, still in its honeycomb cell, encloses itself in a silken cocoon, where it stays as an apparently quiet pupa for 12 days. Actually, many drastic changes take place in the anatomy during that time. At the end of 12 days, the larva begins to move around, loosens the cocoon, and emerges as a sexually imperfect adult female—a worker.

During its lifetime of about six weeks, the worker practices several trades, each in definite order. For the first two weeks it has the duty of providing food—which it brings from storage cells of the hive—for the queen, drones, and larvae. At the end of two weeks the worker is able to produce wax in glands located beneath the abdominal plates. The wax that appears as scales projecting out from the abdominal plates is scraped out by the hind legs, cut, chewed, and molded into suitable size and proper consistency for construction purposes. The worker uses the wax to build new honeycomb cells, each a perfect hexagon, and to repair older, damaged cells. Other duties of workers of this age include housecleaning and guarding the hive against intruders from other hives and from marauders such as field mice.

After this period of inside work the worker becomes a foraging bee, hunting for and bringing back pollen and nectar, often from considerable distances. Most of this material is either fed to larvae or placed in storage cells for future use. When the storage cells are full, they are capped with wax. The oldest bees become water collectors, particularly if the hive becomes too hot—over 30° C (about 95° F). Younger workers take the droplets of water from the old bees and distribute them where needed, while other workers act as ventilating fans by creating air currents with their wings. This helps evaporate the water, thus cooling the hive.

3a



3b

BUILDING THE HONEYCOMB—One of the duties of the worker bees is the construction of the hive (Illustration 3a). Illustration 3b is an enlarged detail showing the workers completing some cells.

The size of the drone is somewhere between that of the workers and the queen. Its wings are longer than the length of its large, squarish abdomen, and its eyes are huge. Drones are unable to feed themselves or to work; therefore, workers must take care of them as well as of the larvae and the queen. Drones develop from unfertilized eggs, appearing only in spring and summer, the period during which mating can occur. Although some drones may be tolerated in the hive after the nuptial flight of the queen, all are ejected and killed as autumn approaches.

Normally, a hive has only one queen, but if the workers believe the egg-laying activities of the queen are slowing down, or if the old queen should die, several larger cells are made or existing ones enlarged. When the queen can no longer reproduce, several of her eggs are transferred to the larger cells; and after the larvae hatch they are fed royal jelly. If more than one new queen hatches, a fight ensues in which one queen must sting all her rivals to death.

An interesting device tells the workers if the queen is still alive and also indicates to them if the hive is becoming overcrowded. A small gland in the mouth of the queen produces a substance, a minute quantity of which rubs off on the workers as they lick and groom the queen. As long as the workers have some of this substance on them, they know that the queen is alive and well. But if the substance is lacking or considerably diminished, the workers begin at once to construct new queen-sized cells. If, because of the presence of too many bees, there is not enough of the substance to go around, the workers become restless; and as this restlessness spreads through the colony, it finally induces the queen to leave the hive, followed by a large number of workers. This is the phenomenon of swarming. The queen usually alights not far from the old hive and the workers form a dense bunch around her. From there scouts go out in all directions until a favorable location is found for a new hive—either a man-made one or a natural one in a hollow tree or under the eaves of a building. Once the queen has been established in her new home, the cycle starts anew—except that she will not mate again.

OVER-WINTERING

At the end of summer and as cold weather approaches, all remaining drones are killed. If the worker was born in the summer, its life is over after five or six weeks; workers born in the autumn, however, live through the winter, as does the queen. In cold weather the bees huddle together in a ball; the colder the temperature, the tighter the ball. The bees in the center naturally stay warmer and constantly move their legs, wings, and abdomens to produce heat. After a while the bees in the center of the ball gradually make their way to the periphery and their places are taken by the other bees. Thus, even in the coldest weather, bees do not freeze.

4

CLOSING THE CELLS—As the cells are completed and filled with food, the workers cap them with wax.

KILLING THE DRONES—The drones are the males in bee society. They appear only in spring and summer during the mating season. After that they may be tolerated and fed for a while, but eventually they are ejected from the hive or killed by the workers.

5

FORAGING AND FEEDING

Bees gather three materials that are not used as food but that are important in the maintenance of the hive. Propolis, or bee glue, a resinous exudation from certain plants, is carried back to the hive in the bee's mouth and is used to make repairs to the hive, to plug holes in the hive, and to seal up the bodies of dead bees and of enemies too large to be removed. Balm, a substance similar to propolis but more liquid, is also probably gathered, although there is some question as to its source. It is used as a varnish to cover the inside of the cells.

The most important forage, however, consists of pollen and nectar, which constitute the basic food of the community. Large quantities of pollen adhere to the fuzzy bodies of the bees as they visit flowers. Special bristly hairs on the legs brush the pollen off the body and roll it into compact balls that are transferred to the concave outer surfaces of the hind legs. The bee then returns to the hive with a load of pollen often heavy enough to cause the hind legs to hang down while the bee is in flight. Nectar—located in nectar glands at the base of the petals of many flowers—is sucked up by the long mouthparts, which are held together so as to form a tube. The nectar is swallowed into the honey crop, a specialized part of the digestive system, where salivary enzymes partially digest the sugar of the nectar. The foraging worker feeds itself by opening a valve at the end of the honey crop, thus permitting some of the nectar to go into its stomach. When the worker returns to the hive, the nectar still remaining in the honey crop is regurgitated onto the mouthparts of younger workers, who aid in the evaporation of water from the nectar by passing it from tongue to tongue. It is then stored, as is excess pollen, in empty storage cells, which are then capped with wax. Further evaporation of water from the honey occurs during storage, thus producing a concentrated honey. During a good season, one hive is capable of producing 1 kg (about 2 lb) of honey per day. Since the pollen and nectar load of a bee is about 5 mg, one day's honey requires an average of 200,000 flights by the 30,000 to 60,000 bees that make up an active beehive.

How bees locate supplies of nectar and communicate the location of their finds to other workers has long been a puzzle. Through extensive observation and experimentation it has been determined that scout bees, by different kinds of dances, convey information as to the distance and direction of pollen and nectar sources. If the food supply is less than 100 ft from the hive, the scout, after depositing a drop of the nectar in the hive, performs a round dance, going in circles until other bees follow suit and eventually leave the hive in search of the food. The scout conveys information about the kind of flower by the scent that it has picked up from the flower at the same time it marked the flower with a drop of its own scent, secreted by a gland at the tip of the abdomen. If the source of food is farther away than 100 ft the scouts go through a more complicated dance, forming figure-eights and wiggling the abdomen in the tail-wagging dance. The speed of the dance indicates the richness of the food source, the duration of the dance indicates the distance of the food, and the orientation of the body in respect to the sun and the food source indicates the direction of the food. In this way food locations can be pinpointed to within 45 m (about 50 yd).

7

QUEEN WITH HER RETINUE—The queen is distinguished from her companions by her longer abdomen and by wings that are short in proportion to the body.

8

FORAGING BEES AT WORK—An essential function of adult workers is gathering pollen and nectar and bringing it back to the hive for immediate consumption or for storage.

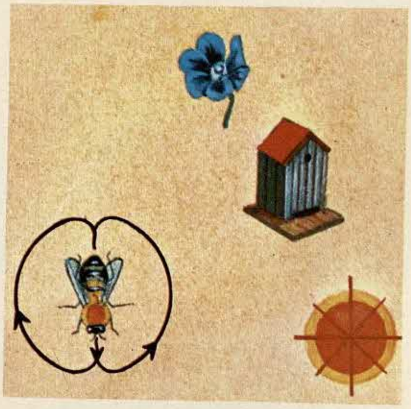
WORKER BEES CARING FOR A QUEEN—The life of the queen lasts about four or five years. During this time she is fed, groomed, and defended by the workers. The large queen in the center of the illustration is surrounded by her attentive workers.

6

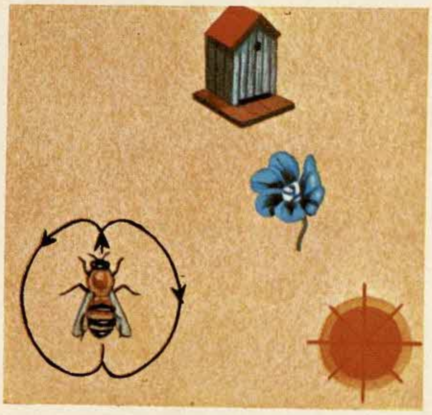
9a

RETURN TO THE HIVE—After gathering nectar, the bees return to the hive (Illustration 9a). They then perform the dances outlined in Illustrations 9b, 9c, 9d, and 9e. The dance varies according to the position of the food with respect to the hive and the sun.

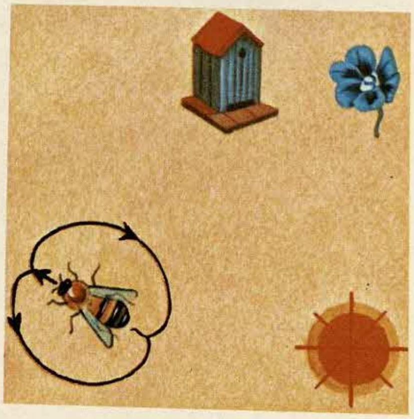
9b



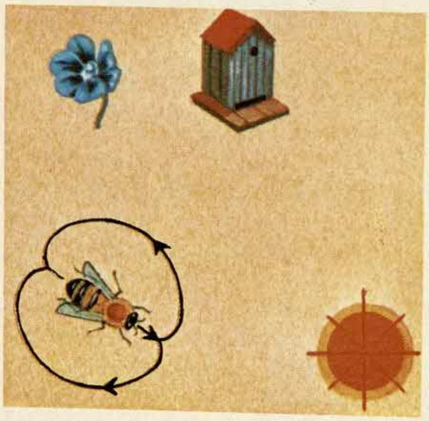
9c



9d



9e



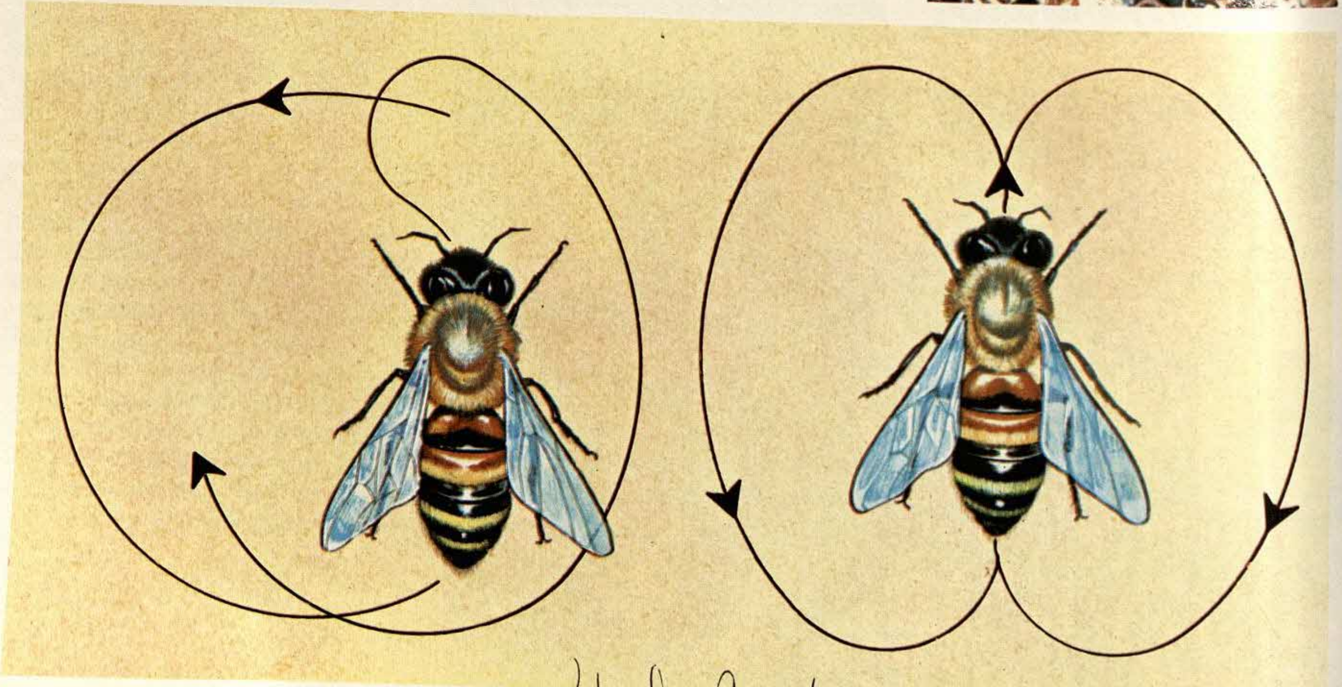
It has been demonstrated that worker bees from different hives can understand the dance of bees of the same variety without difficulty. There is, however, no communication between different varieties of bees.

Communicating information about food sources is not the sole function of the dance; it also furnishes information about possible sites for new homes during swarming.

NECTAR DANCE—In Illustration 10a a bee (top center) is dancing to communicate to the rest of the community the distance, quantity, and direction of the food source. On the left in Illustration 10b, a bee is performing the round dance which informs other workers that the source of food is nearby. On the right, the figure-eight dance indicates that the source of food is at some distance.

10b

10a



PLATYPUS, ECHIDNA, AND KANGAROO

monotremes and marsupials

Mammals are fur-bearing animals that produce live young, but there is a small group of primitive mammals, the monotremes, that lay eggs and another group of mammals, the marsupials, that bear live young so early and so poorly developed that they are nurtured for some time in the mother's pouch. The duckbill platypus and the echidnas are the only monotremes. The kangaroo is but one of many marsupials. The monotremes and most of the marsupials are confined to Australia, New Guinea, and neighboring islands.

DUCKBILL PLATYPUS

The duckbill platypus is the most typical and best known of the monotremes. It is covered with a thick pelt and has webbed feet with claws similar to those of the otter. The feet are suitable both for swimming and for digging in soil. The flat, muscular tail, similar to a beaver's, serves as a stabilizer in swimming. The platypus has a small head and a strong bill that resembles a duck's. For this reason, the early settlers called it the duckmole. Its bill is different from that of a bird, however, being flexible, parchment-like, and extremely sensitive to touch and vibration. By contrast, a bird's bill is rigid and practically insensible. On the hind legs of the male platypus there is a concave spur, similar to the viper's poison fang, which permits the animal to defend itself by injecting a poison into its enemies. Part of the skull and the bones of the pectoral (or shoulder) girdle are constructed similarly to those of reptiles.

The female lays two eggs covered with leathery shells. She incubates them in a burrow for about ten days. Her milk, which is produced in abdominal glands resembling sweat glands, is secreted onto her fur where the young lick it up. The babies are weaned at four or five months.

The platypus lives near freshwater rivers and lakes in eastern Australia and Tasmania. Although it spends only about two hours a day in the water, each animal, especially during the mating season, staunchly defends its own stretch of shoreline, which can be as much as 4 or 5 km (about 2.5 to 3 mi) long.

The platypus, which is exceptionally voracious, spends its day in search of food. Early in the morning and at sunset the animal hunts in the water, diving with its eyes closed and, making use of the great sensitivity of its bill, sweeping the muddy bottom, searching for worms, crustaceans, and tadpoles. It exhausts its reserve of oxygen within a few minutes and returns to the shore, where it chews the food that it has found; then it dives again.

During the day the hunt proceeds on land, where the animal digs in the muddy banks, searching for earthworms, caterpillars, and insects. Within a 24-hour period, a single platypus may eat 1,000 to 1,500 earthworms, 200 to 250 tadpoles, about 100 caterpillars, 50 to 60 crustaceans, and an enormous quantity of insects.

THE ECHIDNA, ANOTHER OF NATURE'S STRANGE CREATURES

The echidnas, or spiny anteaters, are similar to the platypus but somewhat more adaptable. Two genera of echidnas are known. The short-nosed echidna (*Tachyglossus*) lives in forests and dry areas of Australia, Tasmania, and New Guinea. The long-nosed echidna (*Zaglossus*), which has a longer nose and a larger body, lives in the forests of New Guinea.

Both echidnas have stocky, rounded, tailless bodies. Their short, powerful paws are armed with strong talons that curve inward. The dorsal and flank regions are covered with long spines that protect the animals from their enemies. In the long-nosed echidna the spines may be hidden in the long fur. When in danger, the animals either roll into spine-covered balls or burrow into the earth where they anchor themselves by their claws and spines. All four feet are used in burrowing, and the animal literally sinks out of sight. The echidna's strength is proverbial; despite its rather small size, it can move objects many times its weight.

The echidna's diet is highly specialized, for it is limited to termites, ants, and other insects. Like the common anteater (to whom it is not related), it has a long tongue used in obtaining its food.

The female echidna lays a single egg (rarely more than one) and transfers it to a ventral cutaneous pouch that forms only during the season of reproduction; here the egg is incubated for seven to ten days. After the incubation period, the embryo, about 12 mm (about ½ in.) long, perforates the shell with a special egg tooth situated on the tip of its snout and emerges from the egg. The mother's milk flows from pores into the pouch where the baby develops. The egg tooth falls at 18 to 20 days, and by five weeks the infant has paws equipped with claws. When the baby's spines form at about nine weeks, the mother removes it from the pouch and hides it in the underbrush. She continues to nourish it regularly until it reaches full development, apparently at 14 weeks of age.

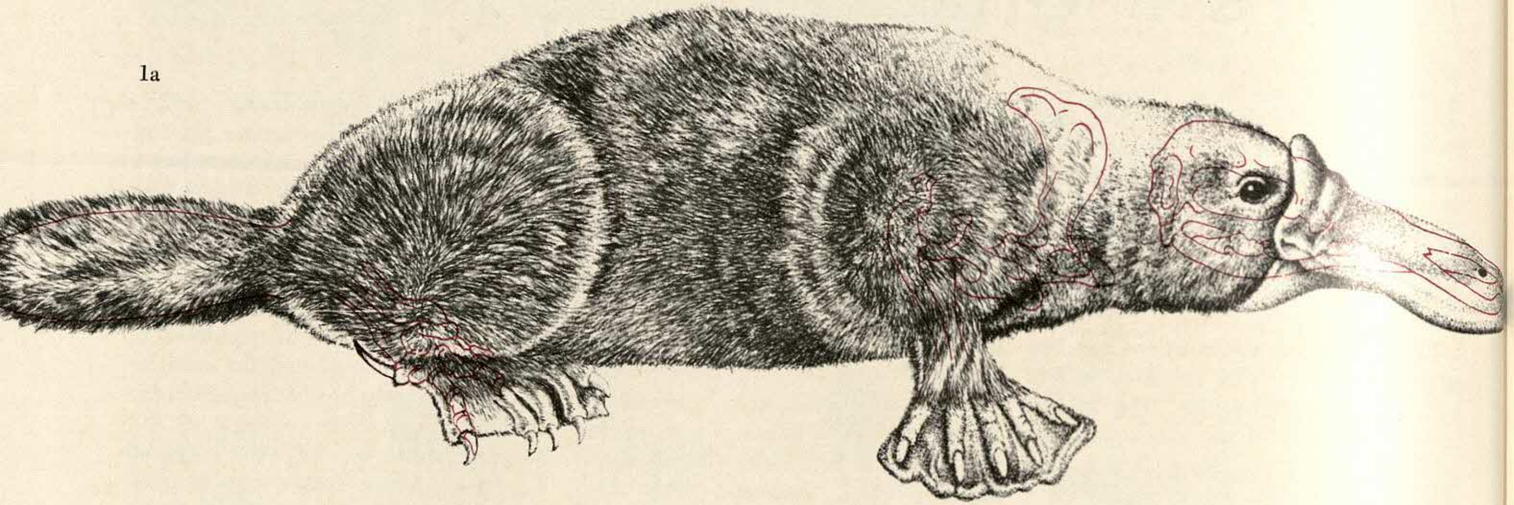
THE METABOLISM OF THE MONOTREMES

The monotremes are neither true homeotherms (warm-blooded animals that maintain a constant body temperature) nor true poikilotherms (cold-blooded animals whose temperature varies with that of their environment). The monotremes have self-regulatory systems and react to temperature for the most part as the mammals do; but their average body temperature is only about 32° C (89.6° F), and it undergoes wide variations. At moments of intense activity, it may reach 35° C (95° F), and in moments of rest it may fall to 22° C (71.6° F). It also rises when the ambient temperature becomes very high and falls when it becomes very low. Although a thermoregulatory system is present, it is not so well perfected as in other mammals.

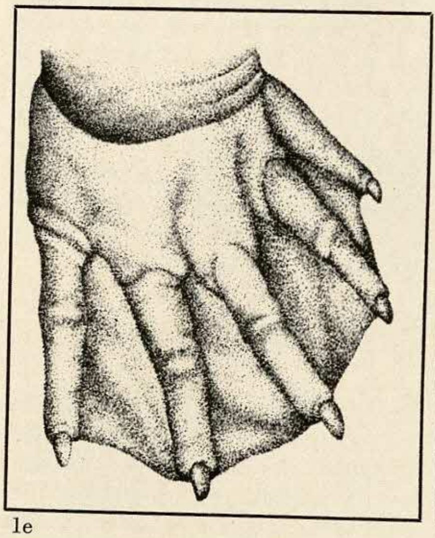
CLASSIFICATION OF THE MONOTREMES

Little is known about the ancestry of the monotremes because few of their fossils

1a



1b



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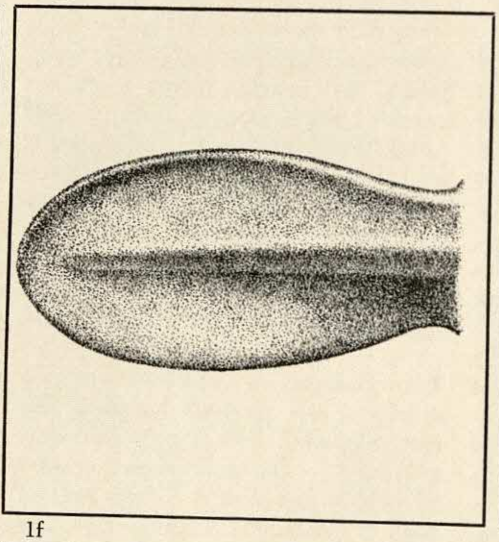
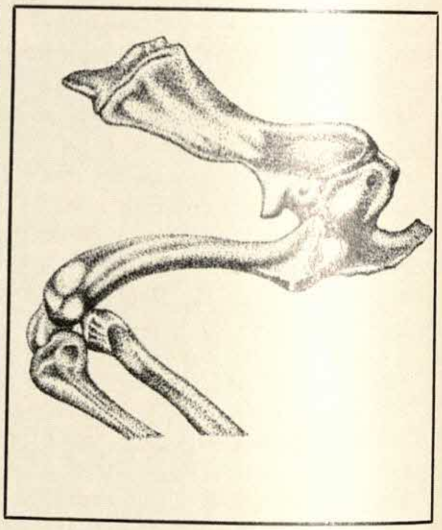
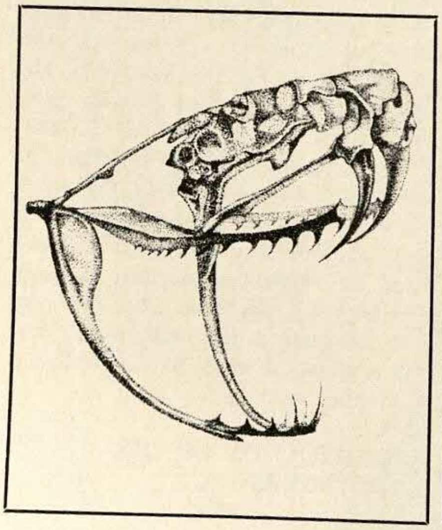


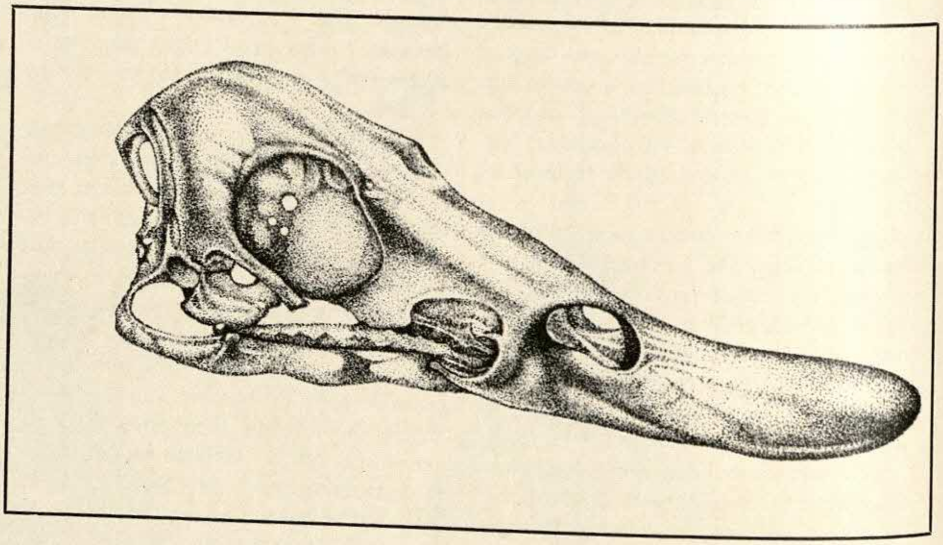
1d



1e



1f



THE DUCKBILL PLATYPUS—The duckbill platypus (Illustrations 1a, 1g, and 1h) is unusual in having features like those of many unrelated animals. Like any other mammal, it has hair. Its swimming abilities depend in part on its webbed forefeet, which resemble those of an otter (Illustration 1b), and its flat tail, which looks like that of a beaver (Illustration 1c). Its reptilian characteristics include the structure of its skeleton; the pectoral girdle resembles that of a crocodile (Illustration 1d). The male platypus has poison spurs on its hind feet that function much like a snake's poison fangs (Illustration 1e). The bill of the platypus looks much like a duck's (Illustration 1f), but unlike the duck's bill it is flexible and has many nerve endings.

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have been found. Their ancestors are believed to have evolved from reptiles during the Cretaceous period more than 100 million years ago. The leathery-shelled eggs of the present-day platypus and echidna, the reptilian features of their skeletons, and their imperfect temperature regulation are all evidence of a reptilian ancestry. But because they have fur and produce milk, the monotremes are classified as the most primitive of mammals. They are rightly called living fossils.

THE MARSUPIALS AS A STEP ON THE ROAD TO PRESENT-DAY MAMMALS

Late in the Jurassic period, at least 135 million years ago, there appeared a new type of mammal, the marsupial. More highly evolved than the monotremes, and endowed with a great capacity for adaptation, it was the beginning of a new evolutionary line from which many species branched. At one time the marsupials were found over nearly all the world, but today only a few species exist outside of Australia, New Guinea, and their neighboring islands. The many species of marsupials are diverse in their characteristics and habits. The carnivorous marsupials include the marsupial mice, marsupial moles, and Tasmanian wolves. The herbivores include kangaroos, wallabies, rat kangaroos, koalas, flying opossums, and phalangers. The omnivorous bandicoot occupies an intermediate position. Some

1g

1h

marsupials are terrestrial and others are tree dwellers.

THE KANGAROO

Kangaroos and wallabies are perhaps the best known of the Australian marsupials. The wallabies, of which there are many species, are not much different from true kangaroos except in size: the smallest wallaby is about the size of a hare.

The most typical kangaroo is the giant red kangaroo, so called because of its great size and reddish pelt. Males may weigh over 70 kg (about 154 lb). Its hind limbs are very strong, and it has a long, strong tail that it uses as a lever. In spite of its weight, it can clear obstacles as high as 1.5 m (about 5 ft) and can jump 9 m (about 30 ft) horizontally. The kangaroo spends its time on the grazing lands of the vast arid central zones of the continent, where its only enemies are the dingo (wild dog) and the eagle, which prey mostly on the younger animals.

At the end of her gestation period, the female kangaroo cleans her abdominal pouch and gives birth to a single infant that weighs only a few grams and is only 25 mm (about 1 in.) long. In a few minutes, the newborn baby climbs into the mother's pouch, where it attaches itself to one of her four nipples. The nipple expands in the infant's mouth and holds it securely in place while it develops further. Only toward the seventh month will the little kangaroo begin to leave the pouch and feed on grass, but it will continue for a long time to seek refuge in the pouch.

A few days after giving birth, the female mates again, but the new embryo remains in a dormant state during the time the offspring of the previous birth sucks its mother's milk. The second embryo does not resume its development until the first infant is weaned or, through some disaster, is lost.

Other marsupials have similar reproductive processes, although some may have large litters, and the size of the offspring and the lengths of their periods of dependency vary according to the family.

RED KANGAROO—The name derives from the brick-red color of the adult male. The females of this species (*Macropus rufus*) are, instead, rather light and sometimes of a grayish blue color. Red kangaroos generally graze in herds, or mobs, in the arid plains of the central zone of the continent.

A YOUNG KANGAROO IN THE POUCH—After birth, the young kangaroo remains in the pouch, attached to a nipple for about six months. Another five or six weeks are required for weaning to be completed, and during this period it continues to live with its mother and often seeks refuge in her pouch.

ECHIDNA OR SPINY ANTEATER—The female of this species (*Tachyglossus aculeatus*) has an abdominal pouch in which she carries her egg until it hatches. The offspring remains in the pouch for two additional weeks while it grows fur and spines.

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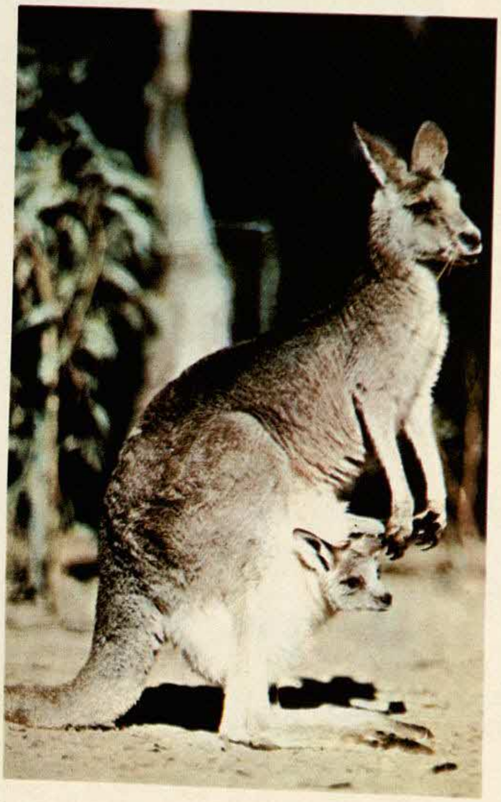

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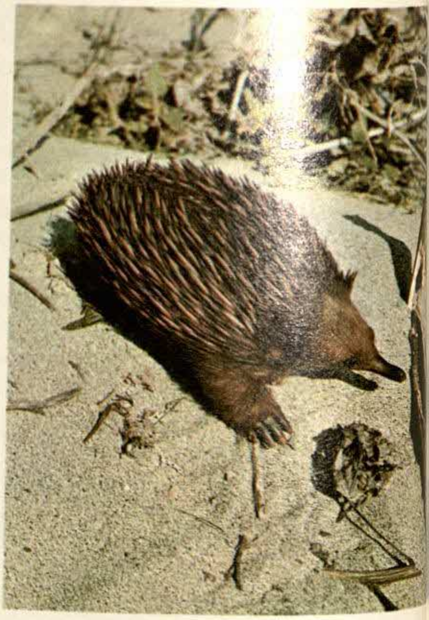

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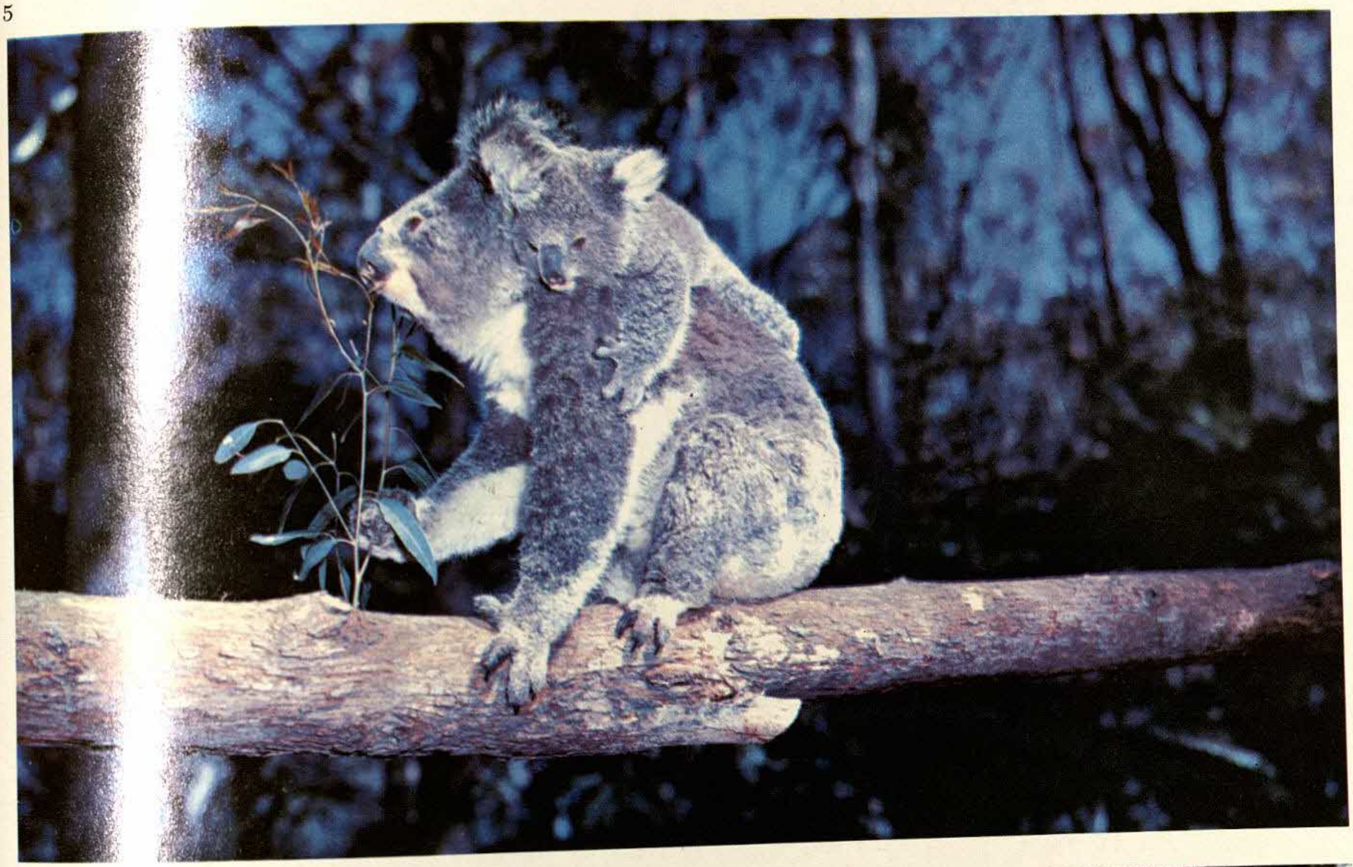

KOALA WITH ITS YOUNG—The female koala produces only one cub every two years; the young animal completes its development in the maternal pouch, where it remains for about six months. Then it clings to its mother's back until it becomes completely independent. The once numerous koalas were killed by disease, trapping, and the destruction of eucalyptus trees, their only food. Now rare, they are rigorously protected by law.

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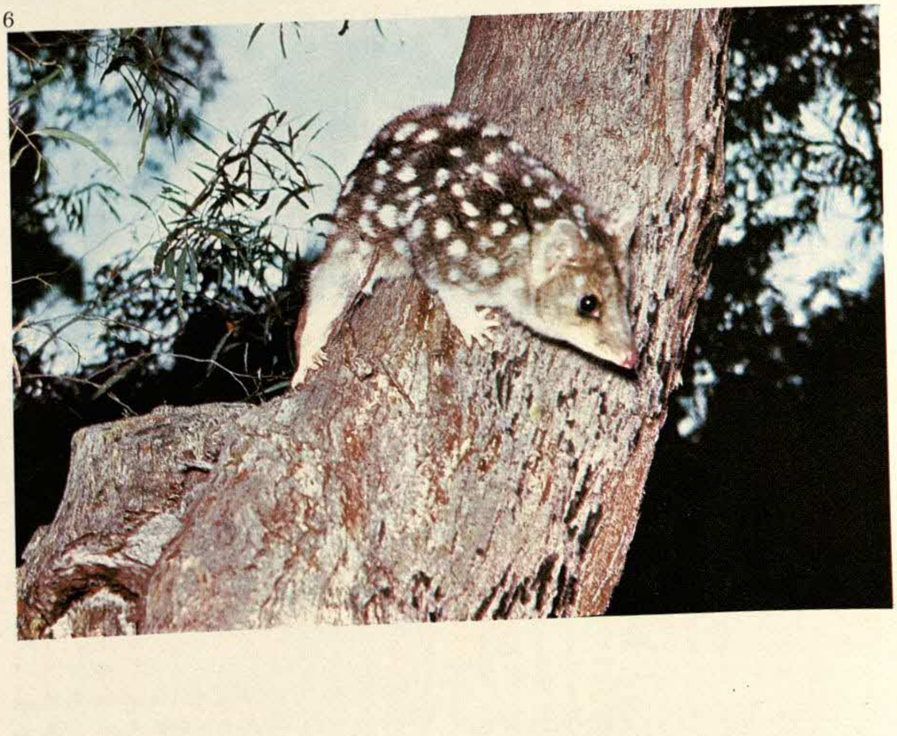

MARSUPIAL CAT—This carnivore lives in tree trunks or under piles of rocks. The adults may be more than 60 cm (about 2 ft) long.

BATS

a highly specialized order of mammals

In some people's minds, bats have a sinister reputation as symbols of hair-tangling terrors, of blood-sucking vampires, of mystery, and of evil. False as such stories are, the truth about bats is interesting enough. Like other mammals, bats (order Chiroptera) are basically terrestrial animals that, during the course of evolution, have become highly modified for life in the air and in the darkness. It is probable that only Cetacea, the order that includes whales, porpoises, and dolphins, presents a greater degree of mammalian specialization. While retaining such mammalian characteristics as internal development of the young, milk, and vestigial hair, cetaceans have secondarily acquired fishlike body forms and finlike flippers. These characteristics, plus the gigantic size of some whales, have enabled them to become the dominant animals of many oceans, where they have taken the place of the extinct ichthyosaurs and plesiosaurs (marine reptiles) of the Mesozoic era. While the cetaceans successfully occupy a habitat almost entirely unused by other mammals, the chiropterans successfully occupy another habitat completely unused by other mammals.

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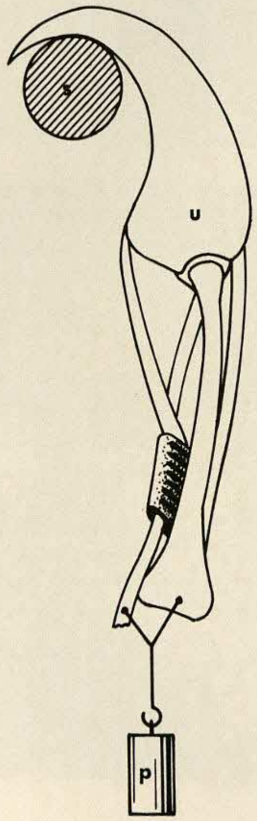


AN UNUSUAL SYSTEM OF HOOKING—When a bat hangs upside down by its hind legs, the weight of the body **p**, acting on the claw **u** as a lever, causes the claw to hook automatically onto the roost **s**.

REVOLUTIONARY ORIGIN OF THE BATS

The fossil record of bats is so incomplete that it is impossible to document their early evolutionary history. The oldest fossils that have been found belong to a species already capable of flying; as a result, it is difficult to hypothesize the evolutionary stages through which some early insectivorous mammal passed before it could fly. It is entirely possible that an extinct Dermoptera, an order represented today by the single genus *Galeopithecus* (the flying lemur), constituted the link between the small, arboreal Insectivora (shrews) of the past and modern bats.

During the Eocene epoch two outstanding bat characteristics were perfected—the ability to fly and the ability to be active in the dark. If bats had evolved only the ability to fly, they probably could not have competed successfully with birds, which were already well established in the air and whose diet of insects and fruits was similar to that of bats. Along with the ability to fly, however, bats also evolved the nocturnal habit that took them out of competition with birds, which are almost all diurnal.

MORPHOLOGICAL ADAPTATIONS FOR FLIGHT

A number of anatomical specializations make it possible for a bat to fly. Some of these parallel the adaptations found in birds; however, the similarities are not due to close genetic relationship but to the fact that only certain structural modifications are possible if a vertebrate is to fly. The modifications in the bat forelimb that enable it to function as a wing involve skeletal and integumentary changes from the basic mammalian plan. All the parts of the forelimb are elongated. The radius is longer than the humerus, and the ulna is reduced and fused to the radius. The greatest elongation is found in the hand, particularly the phalanges (finger bones), where all but the thumb are extraordinarily long. Another skeletal feature of the bats is the rigidity of the thoracic region—a rigidity caused by the fusion of parts of the sternum (breastbone) with each other and with the ribs. In addition, the sternum has a carina (keel) that provides a broad expanse for the attachment of the pectoral muscles, which aid in flight.

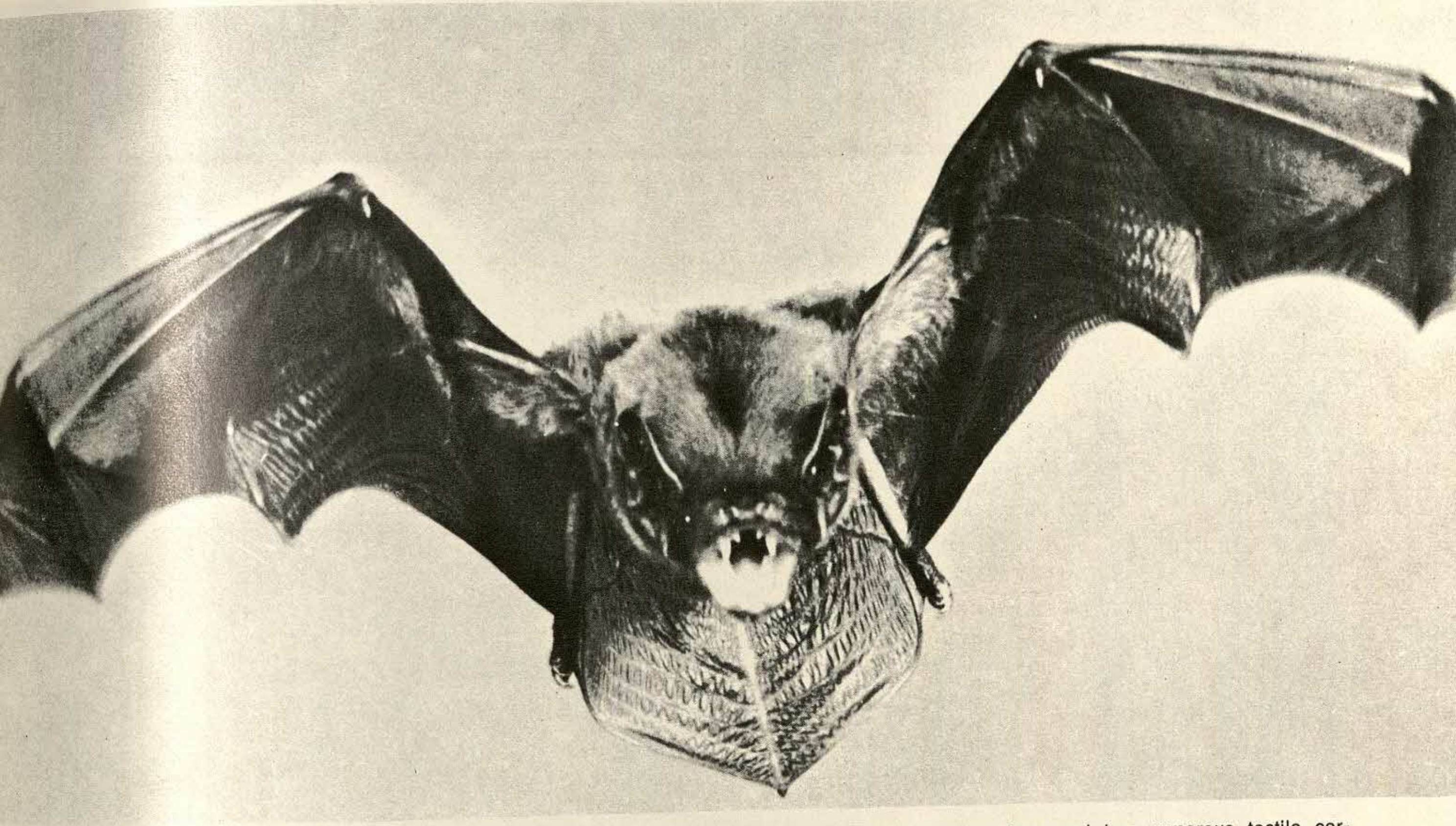
The integumentary modification consists of a double layer of skin, the patagium or wing membrane, that grows out from the sides of the body. This membrane stretches between the fingers of the forelimbs, except for the thumbs, and encases much of the hind limbs, and, in many species, much of the tail. The membrane lacks fur, although a few hairs may be present, and is strengthened by elastic fibers and muscles, which serve to fold the wing when the animal is at rest. Numerous tactile corpuscles in the wing membrane make it sensitive to touch. During flight the hind limbs are held out rigidly to stretch the membrane fully.

DIFFERENT METHODS OF FLIGHT

Although the anatomy of all bats is similar, differences exist in the way in which different species fly. The rhinolophine (horseshoe) bats, which have short, wide wings, fly with an uncertain, butterflylike motion; while the noctule, with its long, narrow wings, flies more directly and more strongly.

Some phases of the flight of these mammals have been analyzed from motion pictures. On takeoff, many species beat their wings a few times, changing their body position from vertical to horizontal as they leave the roost. Others,

2



NOCTULE IN FLIGHT—This vespertilionid bat is characterized by a very small body and a large wingspread. In order to catch and swallow flying insects, many bats keep their mouths open as they fly. Bats evolved from nonflying ancestors that acquired their ability to fly through the transformation of the forelimb into a wing by an enormous elongation of the fingers, which function as tensors to tighten an extended double layer of skin, the patagium. This wing membrane grows out from the sides of the body, covering the forelimbs, almost all of the hind limbs, and, to varying degrees, the tail. The patagium is almost bare and has numerous tactile corpuscles. It contains muscles and a system of elastic fibers that serve to fold the wing when the animal is at rest. Resting bats hang by their feet from branches or outcroppings of rocks or from the ceilings of the caves in which they take shelter.

roosting on the ceiling of a cave, drop vertically, stopping their fall with the first beating of their wings as they begin to fly. In straight flight the bat wing has a rotary motion, as in birds; the front edge of the wing dips down as the back edge comes up. The body is held almost horizontally and is slightly curved when the wings are brought downward. The number of wingbeats per second varies from 12 in *Myotis* to 16 to 19 per second in some pipistrelles and in the noctule. In stationary flight, typical of the species that hunt from the roost, the wing movements are the same but the body is held more vertically. To turn, a bat folds its wings slightly, spreads out the wing in the direction of the turn and at the same time beats the wing on the opposite side very rapidly, four to six beats per second.

Bats usually do not fly very swiftly. The noctule, however, may reach 50 km (about 30 mi) per hour, and the *Miniopterus* 70 km (about 43 mi) per hour. The fastest of all is the American species, *Tadarida brasiliensis*, the free-tailed bat of the southwestern United States, which can reach speeds approaching 100 km (about 60 mi) per hour. This species is highly gregarious and is capable of long migrations.

Landing technique varies according to species. Vespertilionids, for example, straighten out their bodies, slow down by means of the wing membrane, and land with their heads up. Rhinolophines, on the other hand, make a kind of pirouette at the last minute, landing with their heads down.

While at rest during the day, most of the arboreal and troglodytic (cave, or other dark-space-dwelling) species hang by their hind legs, head downward, from branches, outcroppings of rocks, or the ceilings of the caves in which they shelter. Resting bats employ an unusual, automatic hooking device on their hind legs. The claws of the hind legs curve around the roost and are clamped shut by the weight of the hanging bat.

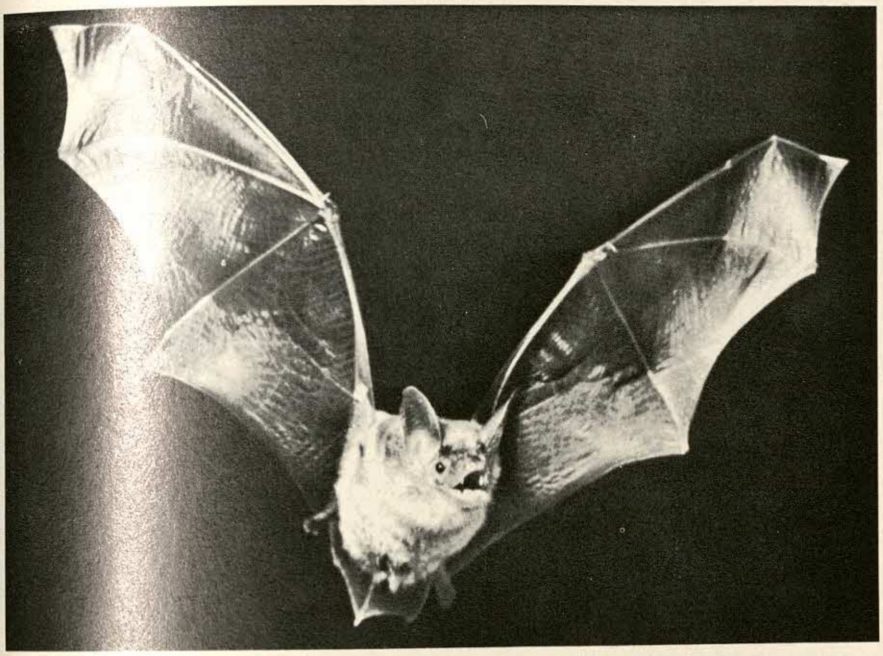
ADAPTATION FOR ORIENTATION IN THE DARK

Because of their remarkable ability to fly and feed in total darkness—an ability that birds lack—bats are able to compete with birds, which inhabit the same environment and live on approximately the same foods. Bats not only avoid small obstacles in the dark but can locate the smallest prey in the dark. This ability occurs only in the insectivorous and

3a

troglodytic species, which, however, comprise the great majority of living bats. Except for the cave-dwelling *Rousettus,* the fruit-eating, arboreal species of the Pteropodidae family do not have this ability. *Rousettus,* like other cave-dwelling bats, is capable of emitting high frequency sounds. The discovery of this phenomenon is rather recent. In 1794 the Italian scientist Lazzaro Spallanzani demonstrated that bats can fly even when blinded. Not until 1941, however, when it was demonstrated that bats emit a great variety of high frequency sounds, was it understood how bats could function so well in the dark. These ultrasonic waves vary in frequency with different bat families and even between different species of the same family. Research concerning methods of ultrasonic wave emission and perception will undoubtedly bring further knowledge of these unusual processes. The most interesting aspect of the variety of high frequency sounds produced is that they appear to be connected to different hunting techniques and to different anatomical specializations. In the *Microchiroptera* high frequency sounds are produced by the larynx, which is equipped with powerful

3b



3c

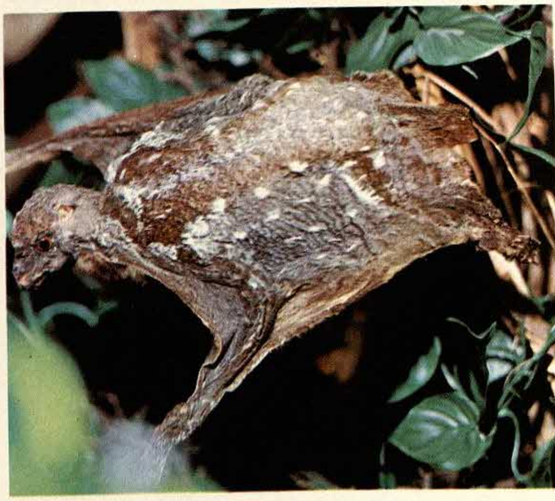
SOME INTERESTING BATS—All bats have essentially the same structure although some show a number of modifications. Illustration 3a shows the greater horseshoe bat in flight; its heavy body and large wingspread are prominent. One of the most peculiar bats is the big-eared bat (Illustration 3b); its ears are three times longer than its head. Illustration 3c shows the mouse-eared bat in flight. Its coat is whitish on the abdomen and gray on the back. The bats hanging from the branches of a tree (Illustration 3d) are known as flying foxes; they fly in groups.

Galeopithecus (Illustration 3e), a mammal belonging to the order Dermoptera, has a patagium that contrasts with the more extensive one found in bats. This animal, like some phalanger marsupials and flying squirrels, glides long distances from high branches.

The most interesting aspect of bat biology is undoubtedly the ability bats have to orient themselves in the dark by means of high frequency sounds. By means of these sounds they can pinpoint the exact location of obstacles and of the smallest prey on the wing.

muscles. In *Rousettus*, a Megachiroptera, the tongue produces high frequency sounds of a simpler type. In the vespertilionids, phyllostomids, molossids, and emballonurids, the high frequency sounds emerge from the mouth, which is kept open during flight. In the rhinolophines the sounds come from the nose, which has a peculiar leafy outgrowth of skin called a nose leaf. This nose leaf seems to play an important role in directing the bands of high frequency sounds emitted. Bats hear the echoes of these ultrasonic waves as the waves bounce back from insects and nearby obstacles. Thus, bats find their prey in the dark.

3d



3e

MIGRATIONS | nature's commuters

1

A FLOCK OF FLAMINGOS PREPARING TO MIGRATE—Flamingos abound in Sardinia; in the summer they seek a cooler climate and may be seen arriving in flocks on the southern coast of France.

Each year millions of birds pass through the spring skies, leaving their winter homes to fly north to their summer breeding grounds. There they raise their young, and in the autumn they head south again for their winter homes. Such round trips by animals are called migrations.

Migrations are regular, often annual trips that follow definite patterns. They occur only at certain times of year, often with only a few days' variation from year to year. The routes used are identical to those followed by thousands of generations of ancestors, and the destinations, too, are of long standing.

Although birds are perhaps the best-known migrant animals, many mammals migrate, as do some fishes, and even a few reptiles and insects. Migration is not always in north-south directions; European eels, for example, migrate in an easterly direction from their hatching grounds in the Atlantic Ocean to the Mediterranean Sea or northeasterly to the shores of Norway.

The movement of large numbers of animals in one direction only, without return to the point of origin, is known as an emigration. Emigrations usually occur at irregular intervals and may be caused by overpopulation or a depleted food supply. Remigration is the return by a second generation of animals to the region from which the first generation emigrated; this phenomenon is more common among insects than is true migration.

A migration is undoubtedly the most important and perilous adventure that many animal species must face. Many thousands of those who undertake the journey do not arrive at their destination but die along the way. Although the precision of their navigation is almost unbelievable, migratory animals do not possess a system of weather forecasting; and since their journeys often take place during the periods of greatest weather disturbances, they are subject to great danger.

The most dangerous enemies of migratory birds are the strong air currents of storms, which blow the birds off their habitual routes, sometimes over vast expanses of water where they cannot find land on which to rest. Instances of natural disaster are frequent and their causes varied. For example, on the night of March 13, 1904, an immense flock of snow buntings was surprised on the way to its summer home in the Arctic by a late but severe blizzard over Iowa and Minnesota. Cold, weighted down with snow, and disoriented, the birds lost altitude and flew into trees and buildings over a vast area. The disaster was almost total; in one square kilometer (about 0.4 sq mi), 375,000 dead birds were counted.

When fog occurs along a migration route, civilization adds a new enemy to the birds' natural foes. The disoriented birds are attracted by any luminous object, which they perhaps mistake for a directional reference, and they change their course or descend in hedgehopping flight toward the light, colliding with the ground and with trees. After one foggy night at a Georgia air base, the bodies of 50,000 birds that had been attracted by a beacon light were counted. This type of accident occurs frequently at foggy airports located along migration routes. The benefits of migration obviously offset the losses, or migratory species would in time become extinct.

THE ADVANTAGES OF MIGRATION

Despite the dangers of migration, animals continue to make their long journeys year after year. For those animals that travel from tropical or temperate regions to breeding grounds at higher latitudes, one advantage seems to lie in having longer days in which to find food and to tend their young. Both they and those species that remain the year around in warmer climates benefit by not having to compete with each other for food or territory. The return journey in autumn is necessary if the animals cannot endure the rigors of winter.

MIGRATIONS OF BIRDS

Among migratory birds, the Arctic tern holds the record for distance traveled, some birds flying round trips of 40,000 km (about 25,000 mi) between the Arctic and the Antarctic each year. They have been known to fly from Labrador to the southeastern coast of Africa, a journey of about 15,000 km (about 9,300 mi) in 90 days.

The best-known migratory bird of Europe is the white stork, which travels

from the northern countries toward Africa, following one of two different routes that detour around the Mediterranean Sea to reach South Africa. In its flight of 16,000 km (about 10,000 mi), this stork takes advantage of the rising air currents and glides almost half the total distance of its journey. The Adélie penguins of the Antarctic spend much of their time at sea, but as the breeding season approaches, these flightless birds walk hundreds of miles over snow and ice to their inland breeding grounds.

MIGRATION OF MAMMALS

Alaskan fur seals are born in the spring in the Pribilof Islands in the Bering Sea west of Alaska. Shortly after they give birth, the females mate again with the males, but they devote the rest of the summer to raising their pups and feeding. In late autumn the females and their pups migrate 5,000 km (about 3,100 mi) to the coast of California. Here they spend the winter; in spring they return to the Pribilofs where the pups conceived the previous year are born. The adult males do not accompany the females on their long migrations but spend the winter in the Gulf of Alaska.

Whales also migrate great distances. During the summer, the California gray whales feed in the rich waters of the Arctic Ocean. Here they eat enough to sustain them on their migration to California and Mexico, where they give birth to their calves in coastal lagoons.

MIGRATIONS OF FISH

Among the fish are migrants that make long and strenuous journeys. Anadromous fishes are those that live their adult lives in the ocean but breed in fresh water. Salmon are famous for their long upstream journeys in which they leap over waterfalls to reach quiet upland streams. Here the exhausted adults lay their eggs, fertilize them, and then die. The young salmon swim downstream to the ocean where they live for several years until they are sexually mature. Then each salmon returns to the river in which it was spawned. Slight differences in the chemical composition of the water enable the salmon to select the correct tributaries as they move upstream.

Catadromous fish spend their adult lives in fresh water but breed in salt water. The eels that live in the streams of Europe and the eastern United States are spawned in breeding grounds in the Sargasso Sea, a region of the Atlantic Ocean east of the West Indies. They migrate to Europe or North America where they live in rivers until they are sexually mature, at which time they are

2a

AQUATIC MIGRATORS—Illustration 2a shows sardines, which swim in compact schools in spring and summer. Females lay eggs near coastlines and fertilization takes place. Illustration 2b shows tuna, which migrate periodically, generally in relation to variations in water temperature and salinity. Tuna are most often found in the temperate and tropical zones of the Atlantic, Pacific, and Indian Oceans.

2b

3

GOLDEN PLOVER—The golden plover lives in northern Europe, migrating in the winter to Italy and to Africa as far as the Cape of Good Hope. These plovers usually travel when the sky is cloudy and when there is mist. They fly at high altitudes and cannot always be seen from the ground.

ready to return to the Sargasso Sea.

MIGRATIONS OF REPTILES AND INSECTS

Most reptiles do not migrate great distances, but the green turtles that hatch from eggs laid on Ascension Island in the Atlantic Ocean migrate to feeding grounds in Brazil. When they are mature, they return to their birthplace. This trip of over 2,200 km (about 1,400 mi) is all the more remarkable because Ascension Island is only 11.5 km (about 7 mi) long, a small target in a large ocean.

One of the few true migrant insects is the monarch, or milkweed, butterfly. Adults make an annual round trip from the northern United States and southern Canada, where they were hatched, to the southern United States, where they spend the winter in hibernation, then back north where they lay their eggs on milkweed plants.

Locusts are long-distance travelers, but because they are short-lived, they do not make round trips. Their travels are remigrations, not true migrations. The locusts of northern Africa and the Middle East are much dreaded because they move in great hordes that devour all the green vegetation in a few hours. When they move on to new territories, they leave complete devastation behind them.

STUDIES OF MIGRATIONS

Scientists investigate migrations by capturing animals, marking or tagging them, and freeing them. When these animals are observed again, the dates and locations are recorded. Small radio transmitters are attached to some animals so that their journeys may be easily followed. The data collected by these means have furnished important information on routes, speeds, and distances. Average migratory altitudes of birds are about 200 m (about 650 ft) and may be as high as 1,000 m (about 3,000 ft) or more for some species. Small birds rarely exceed 50 km (about 30 mi) per hour in speed, but some larger birds fly at almost double that rate. Many species of birds travel several hundred miles each day of flight.

The most remarkable aspect of the migratory phenomenon is the ability of animals to find their way over long distances. Some young animals may learn their routes by following their parents and observing landmarks as they go; but others, such as the monarch butterfly, have no one to lead them, for the parent generation has died by migration time. Birds flying over wide oceans have no landmarks below to guide them.

Evidence indicates that birds and some other animals navigate by the sun or stars if these are visible to them. In one experiment, birds were caught at autumn migration time and placed in a planetarium. When the planetarium dome was arranged so as to duplicate the natural sky of that time of year, the birds oriented themselves in the proper direction for

LEMMING—The lemming, a small rodent, is an inhabitant of the tundra. Periodically, depending on population increase and the consequent shortage of food, lemmings migrate in masses toward regions that are richer in vegetation.

4

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REINDEER—The reindeer, a native of northern Europe and Siberia, migrates each autumn toward more southerly forests. These animals follow the same route each year.

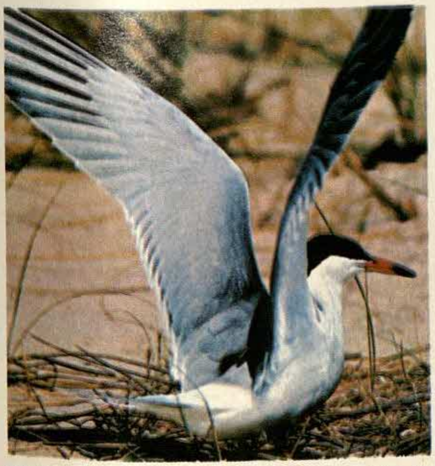
EGRETS—Egrets are found in great numbers in temperate and tropical zones, especially in America. In April and May they migrate to the warmer climates of Latin America.

6

7

WILD DUCK—In spring, many ducks migrate to the colder regions of the north—Lapland, Greenland, and Siberia—and in autumn they return to the temperate regions. These birds travel at high altitudes in the characteristic V-shaped formations, in swift, strong, and continuous flight. They travel remarkably long distances without stopping.

8



TERN—Terns are found in many regions of the world from the equatorial regions to the Arctic. Several species are long-distance migrators.

migration. When the planetarium dome was turned only a few degrees clockwise or counterclockwise, the birds changed their orientation to coincide with this shift.

Even more remarkable is the fact that some animals continue to migrate during fogs or storms—when there are no visible navigational clues. The possibility exists that the animals may be sensitive to the Earth's magnetic field, which varies with latitude, and thus may use this sensitivity in navigation.

Another remarkable feature of migrations is the accuracy with which they are timed for the same month or week each year. The northward movement of birds in the spring follows an increase in sex hormone levels and an enlargement of the reproductive organs. Experiments have demonstrated that these internal changes are controlled, at least in part, by the lengthening days of spring. This explains why migrations often follow the calendar and not the weather, which varies from year to year. Even the specific time of day is pertinent in migration. Many small birds and also larger birds that depend upon vegetational cover fly by night. Nocturnal migrants include rails, cuckoos, thrushes, and wrens. Small insectivorous birds migrate at night, presumably because their prey is active by day. Fast-flying birds, birds that live in the open, and those that capture their food on the wing migrate mostly by day. These include hawks, crows, and swallows.

The appearance and disappearance of birds with the seasons came to the attention of man long ago. There are references to bird migration in ancient literary works, including the Old Testament, *The Sacred Books of the East,* in Sanskrit, the Finnish epic poem *Kalevala,* and in Homer's and Aristotle's writings.

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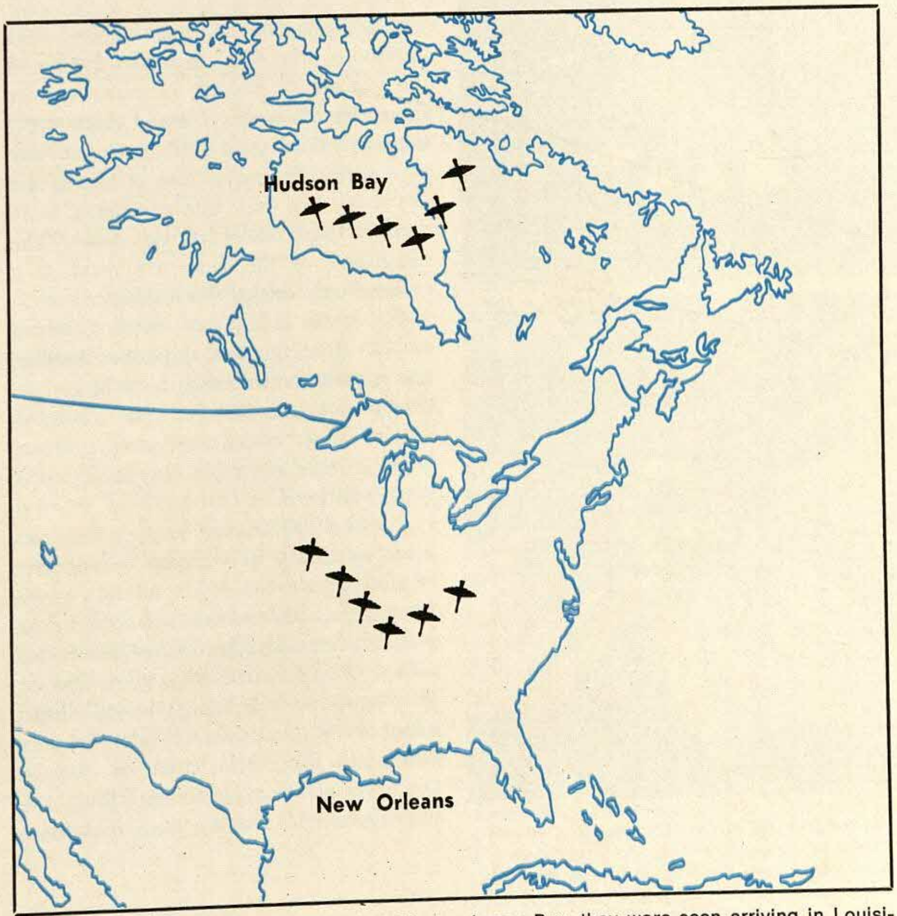

THE LONG FLIGHT OF THE BLUE GOOSE—This map shows the route taken by a flock of blue geese observed in 1952 in North America. Sixty hours after they left the region south of James Bay, they were seen arriving in Louisiana, 2,700 km (about 1,700 mi) away. The starting point of the migration was probably in the region of Hudson Strait.

SEXUAL DIMORPHISM | morphological characteristics and sex

In both the plant and animal worlds it is almost impossible at times to tell whether a living thing is male or female. The morphological characteristics that differentiate the two sexes are not always clear or readily visible; in fact, sometimes the difference is apparent only at the gonadal level. In most cases, however, the male and female can be clearly distinguished because of a complex of specific physical characteristics known as secondary sexual characteristics. (The primary sexual characteristics are the reproductive organs.) This phenomenon is called sexual dimorphism.

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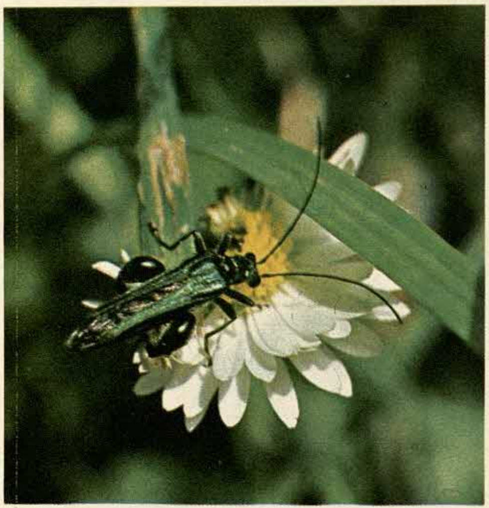

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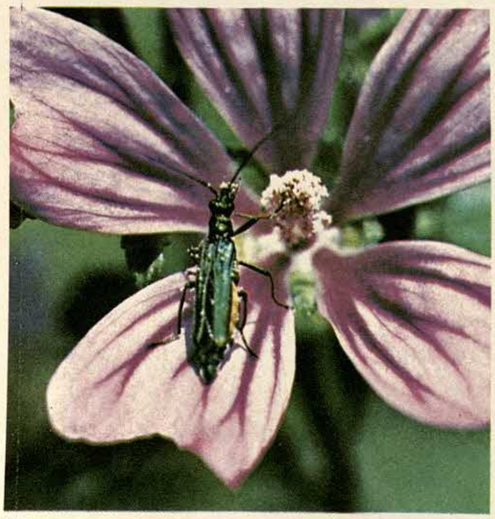


OEDEMERA NOBILIS—The beetle *Oedemera nobilis* is a constant visitor to wild flowers. It is characterized by a clearly visible sexual dimorphism, permitting immediate recognition of the male (Illustration 1a) and the female (Illustration 1b). The male is characterized by thick hind legs, while the female's legs are uniformly slender.

In many species these differences are caused by the presence of male or female hormones in the body. In the simplest forms of animal life, especially among the Protozoa, the sponges, the coelenterates (jellyfish and hydra), and some worms, the animals are not morphologically differentiated into males and females, even though they may be physiologically of different sexes. In other cases a single individual may have both male and female reproductive organs; such individuals are known as hermaphrodites.

SEXUAL DIMORPHISM IN INSECTS

The male stag beetle, as an example, has enormous branched mandibles similar to the antlers of a stag. In some species these mandibles are 50 mm (about 2 in.) long, half the length of the entire animal. In contrast, the mandibles of the female are short, but their bite can inflict more damage than those of the male. The mandibles of the male are used as a weapon only during the mating season.

The male lamellicorn beetles, which include June beetles, Japanese beetles, and scarab beetles, often have larger antennae than the females. The antennae of male June beetles terminate in several lamellae that resemble the leaves of a miniature book.

The Drilidae is a family of beetles parasitic on snails; its wingless females are larger than the males but retain a larvalike shape. The larvae, covered by an outer skeleton of a hard substance called chitin, prey on snails that they devour; they temporarily inhabit the snail shells, using about two or three shells per year. Inside the shells the larvae go through a gradual metamorphosis until they have undergone the molting that transforms them into adults; the female grows in size but its appearance remains larvalike.

SEXUAL DIMORPHISM IN THE CRUSTACEANS

Some copepods, *Cyclops* for example, are only slightly dimorphic. The male, somewhat smaller than the female, has curved antennae suitable for grasping during mating. Some female copepods are parasitic on marine fish; these females are so modified for their parasitic life that they are barely recognizable as copepods.

Most barnacles are hermaphrodites, but in some species certain individuals are males that are parasitic on their hermaphroditic hosts. The parasitic males, like many other parasites, are much smaller than their normal counterparts and have no digestive systems. Those that live inside their hosts are smaller than those that live on the surface. Sometimes they cause the regression of the male reproductive organs of the host, which then becomes functionally female, for only the female reproductive organs remain active. This is an unusual case of sexual dimorphism.

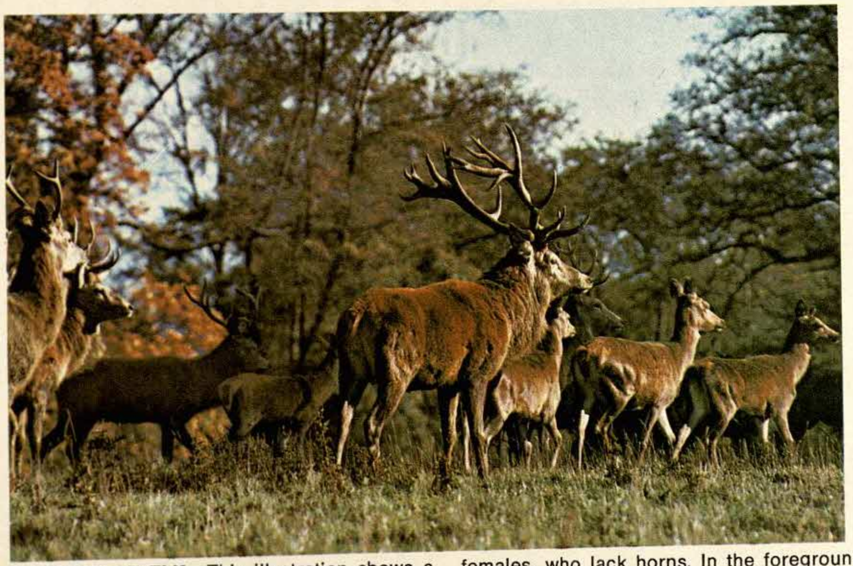
BONELLIA VIRIDIS

Bonellia viridis belongs to the Echiuroidea, a small suborder of worms living in mud or sand. The soft ovoid body of the female is about 2.5 cm (about 1 in.) long; its proboscis, which branches near the tip, may be as long as 1 m (about 3 ft). The male is much smaller, its length not exceeding 1 mm (about 0.04 in.). The male resembles a larva in most respects, but its reproductive organs are completely developed. It lives as a parasite in the body of the female.

A *Bonellia viridis* larva has the capability of developing into either a male or a female. If the larva happens to settle on a female of the species and attaches itself to her proboscis, it develops into a male. This is caused by the female's secretion of special hormones that induce male development of the larvae. Parasitism of males on females is probably an adaptation that solves the problem of finding mates. Larvae that make no contact with females develop into females. Temporary contact with a female causes the larva to become an intersexual individual.

2a

2b **REGAL COUPLE**—Many examples of sexual dimorphism are found among mammals. The lion (Illustration 2a) and the lioness (Illustration 2b) are easily distinguishable, not only because of the considerable variation in their size but principally because of the difference in their coats. The male has a thick mane that the female lacks.



3

A GROUP OF ELK—This illustration shows a herd of elk, in which sexual dimorphism is immediately evident. At the far right are the females, who lack horns. In the foreground is a splendid male specimen with large branched antlers.

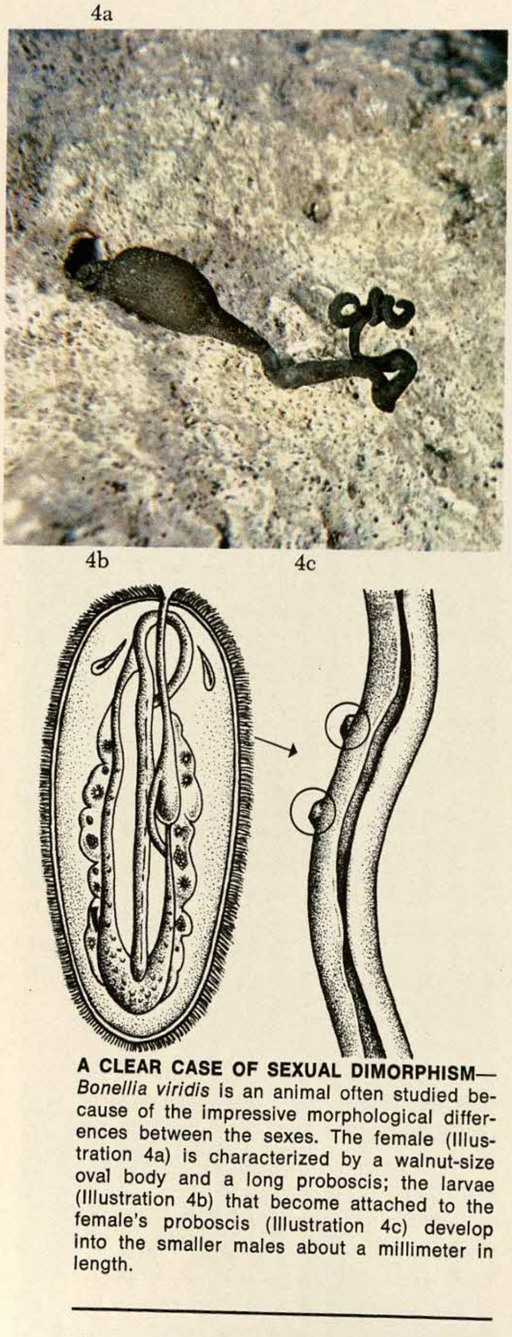
SEXUAL DIMORPHISM IN FISH

Several species of deep-sea fish also have parasitic dwarf males that attach themselves to the heads or sides of the females. Many of these are anglerfish, the females of which have an appendage extending from their heads. A lure at the tip of the appendage attracts prey, which is eaten by the females. The males have no such organs but their mouths are modified in such a way that their circulatory systems unite with that of the females from whose bloodstream they obtain their food. The difference in the sizes of the two sexes is usually marked. One female specimen of *Ceratium holbolli* 1 m (about 3 ft) long carried two males 85 and 88 mm (about 3.5 in.) long. A female specimen of *Edriolychnus schmidti* 70 mm (about 3 in.) long had three males attached to her; each was about 18 mm (about 0.7 in.) long.

SEXUAL DIMORPHISM IN BIRDS

Sexual dimorphism is well developed in birds—the males of many species, for example, are more brilliantly colored than the females, which sometimes have very dull plumage. Examples are cardinals, scarlet tanagers, red-winged blackbirds, and indigo buntings. The inconspicuous coloration of the females affords them protection when they sit on their eggs or chicks in the nest. In other species, such as the blue jay or robin, the two sexes are similar.

Some of the markings borne by one sex are recognition marks by which the birds determine the sex of other members of the species. The male yellow-shafted flicker has a dark mark on both sides of its bill. When similar marks were painted experimentally on a female flicker, her mate would not permit her to approach



A CLEAR CASE OF SEXUAL DIMORPHISM— *Bonellia viridis* is an animal often studied because of the impressive morphological differences between the sexes. The female (Illustration 4a) is characterized by a walnut-size oval body and a long proboscis; the larvae (Illustration 4b) that become attached to the female's proboscis (Illustration 4c) develop into the smaller males about a millimeter in length.

their nest; instead, he drove her off as he would a male bird that had entered his territory. She was permitted to return only after the experimenter had removed the marks.

Sexual dimorphism is also used in the courtship dances in which male birds display their plumage to their prospective mates. Prairie chickens have traditional courting grounds where the birds gather at mating time; here the males dance before the females and use the inflatable air sacs on either side of their necks to make loud booming sounds.

In some species, like the red-winged blackbirds, both sexes display to each other. The peacock has especially colorful plumage of chestnut brown enhanced by oval spots of metallic violet and green, as well as a long tail that is spread into a magnificent fan before the female (the peahen). The female has more subdued colors and a shorter tail.

The male Brown Leghorn fowl has long, drooping, golden feathers in the saddle tract, while the corresponding feathers in the female are short, round-tipped, and stippled. Experiments have proved that the female type of plumage in this breed is caused by an ovarian hormone. The hormone seems to suppress the development of the male type of plumage; for when the ovary is removed, the female Brown Leghorn grows typical male plumage. Castration of the male, however, does not modify its plumage. Upon injection of ovarian hormone into normal males or females from which the ovary has been removed, both grow female plumage.

Experiments performed on breast feathers of castrated male Brown Leghorns resulted in the formation of feathers that exhibit alternate bands of male and female coloration and structural characteristics. First an area of feathers was plucked and growth of the black male-type breast feathers was allowed to start. Daily injections of ovarian hormone were administered for several days, resulting in the growth of salmon-colored feathers typical of the female breast feathers. When the injections were then discontinued, the next basal levels of the feathers that formed after a drop in the ovarian hormone level were again black. Repeating this process throughout the formation of the feathers results in a visual record of changes in the hormone level.

Other kinds of hormones cause the sexual dimorphism of plumage in certain other birds. African weaver finches, for example, develop this dimorphism regardless of whether their gonads are removed. Development of the male type of plumage in these birds depends upon secretion of a luteinizing hormone produced by the anterior pituitary gland. If this hormone is injected into male or female African weaver finches out of the breeding season, or into castrated males or females, they develop the showy yellow and black plumage that is typical of the male.

5

A PROBOSCIS MONKEY FAMILY—The male proboscis monkey, *Nasalis larvatus*, has a large, flat, pendulous nose. The female (on the left) has a slightly enlarged nose that points upward.

SEXUAL DIMORPHISM IN MAMMALS

Among elk, moose, and other members of the deer family, males have antlers that are used in contests with other males at breeding time and for defense. The antlers are shed each year and replaced by new ones. Except for reindeer and caribou, females do not have antlers.

In several mammals, males are conspicuously larger than the females. Among them are sea lions, fur seals, elephant seals, and walruses. The male elephant seal has an elongated snout, which is inflated when the seal makes its great roaring sound. Both male and female walruses have tusks, but the male tusks are longer. Primate male sexual adornments that apparently serve to attract females include whiskers, beards, and brightly-colored hair or skin patches.

THE LOCOMOTION OF AQUATIC ANIMALS | swimming techniques

The ability of different animals to move about in their environments is a characteristic that has always been the subject of much curiosity. Means of locomotion vary with local conditions. Whether they be fins, legs, or wings, all are appropriate under different conditions, and all have evolved under those conditions in which they best serve animals.

LOCOMOTION BY SAIL AND LOCOMOTION BY JET PROPULSION

Because life began in the sea, some of the most primitive forms of locomotion are found in aquatic animals. A few utilize a method of moving through water that is very similar to the movement of a sailboat. This is passive locomotion, in which the animal has no control over its travels but is at the mercy of the wind. The Portuguese man-of-war (a member of the phylum Coelenterata) is actually a colony of hundreds of small animals. The colony is topped off by a large gas-filled float that extends above the surface of the sea and acts like a sail in the wind. The direction and speed of the Portuguese man-of-war are, therefore, dependent on the direction and speed of the wind.

Squids and cuttlefish (of the phylum Mollusca) move by jet or reaction propulsion. The bodies of these animals are loosely covered by tough mantles. Water enters the space between the body and the mantle. When the animal suddenly contracts the mantle, a strong jet of water is forced out through a short, flexible tube known as a funnel. By reaction, the animal moves in a direction opposite to that of the water jet. By changing the position of the funnel, the animal controls the direction of its own movement. Although the octopus can also move by this means, it usually employs the many suckers on its eight tentacles to move over rocky sea bottoms.

Jellyfish (of the phylum Coelenterata) are shaped like bells with tentacles trailing from the rim of the bell. Contraction of the bell forces out a jet of water that propels the jellyfish in an upward direction. The animal has little control, however, over its horizontal movements, which depend on ocean currents.

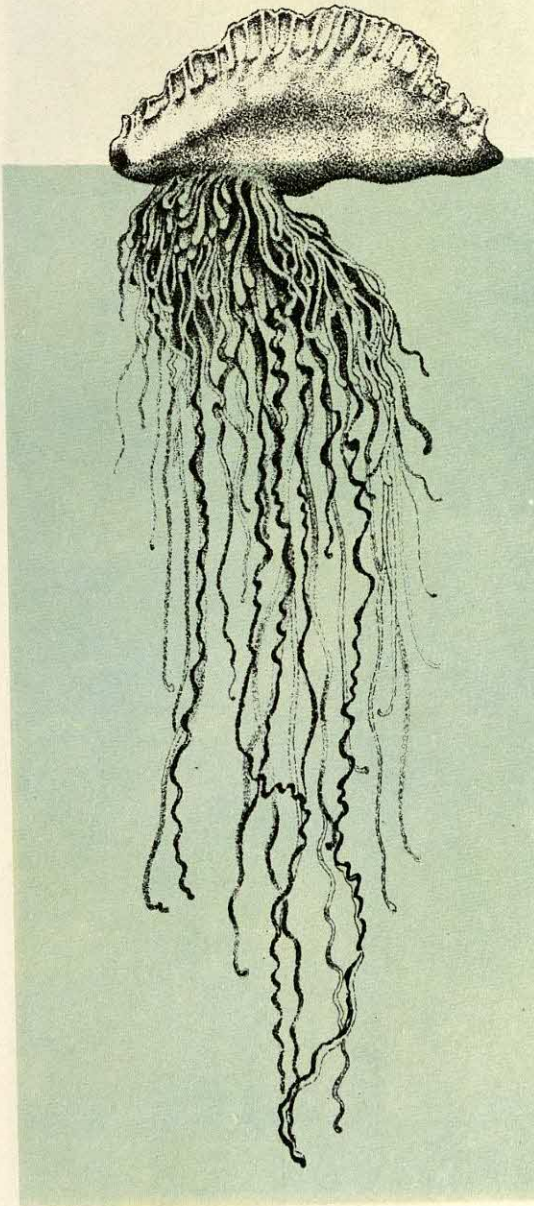
LOCOMOTION BY FIN

Some of the best swimmers have streamlined bodies tapered at both ends, with a fin, known as the caudal fin, at the rear. The caudal fin of a fish is oriented vertically and is moved rapidly from side to side when the fish moves forward. The caudal fin of a dolphin is oriented horizontally and is moved up and down during swimming. The propulsion principle is the same in both cases. As the body of a fish twists sideways, water is pushed in both a sideways and backward direction with respect to the axis of the fish's body. The inertia of the water resists this movement and exerts on the fish's body a force equal and opposite to the force exerted on the water by the fish, thus pushing the fish forward.

To the right and left of its backbone, just beneath the skin, a fish has numerous muscle fibers that control the tail by contracting alternately; when the fibers on the left side constrict, those on the right side relax, and the tail moves to the left. Because the front part of a fish's body is much larger than the back, the front can move forward without oscillating like the tail. Although an eel has a poorly developed caudal fin, it swims with great agility. The length, slenderness, and flexibility of the eel's body all contribute to its ease of movement.

Every time a fish pushes itself forward, it uses some energy. The streamlined shapes of fish and of such aquatic mammals as dolphins and whales help to reduce the amount of energy required; hydrodynamically, such shapes provide minimum resistance to fluids. Herrings are a perfect example.

1



LOCOMOTION BY SAIL—The Portuguese man-of-war is a colony of individual animals (zooids) that have different functions. One large, gas-filled zooid forms a float that acts like a sail. Some are feeding zooids, others are reproductive, and still others have long tentacles equipped with a powerful poison.

SQUID (*LOLIGO VULGARIS*)—The squid moves by a system of jet propulsion, expelling water forcibly from its funnel. It moves in a direction opposite to that of the water it expels (Illustration 2).

2

3

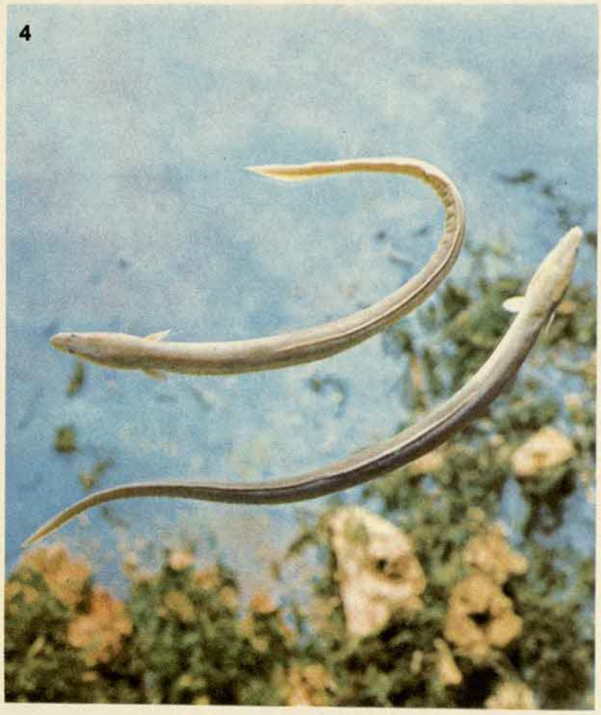
COTYLORHIZA TUBERCULATA—One of the planktonic Scyphomedusae (Scyphozoa), this jellyfish drifts on the current or moves by contracting its umbrella rhythmically (Illustration 3).

SALMON—The salmon is an expert swimmer, using a sculling system to swim upstream and leap up waterfalls and rapids (Illustration 5).

EEL—Despite the smallness of its caudal fin, the eel's slender, streamlined body wriggles through the water with great agility (Illustration 4).

LOGGERHEAD TURTLE—This turtle lives in the warm seas of the Atlantic and Pacific and swims by using its strong, flat limbs as paddles (Illustration 6).

4



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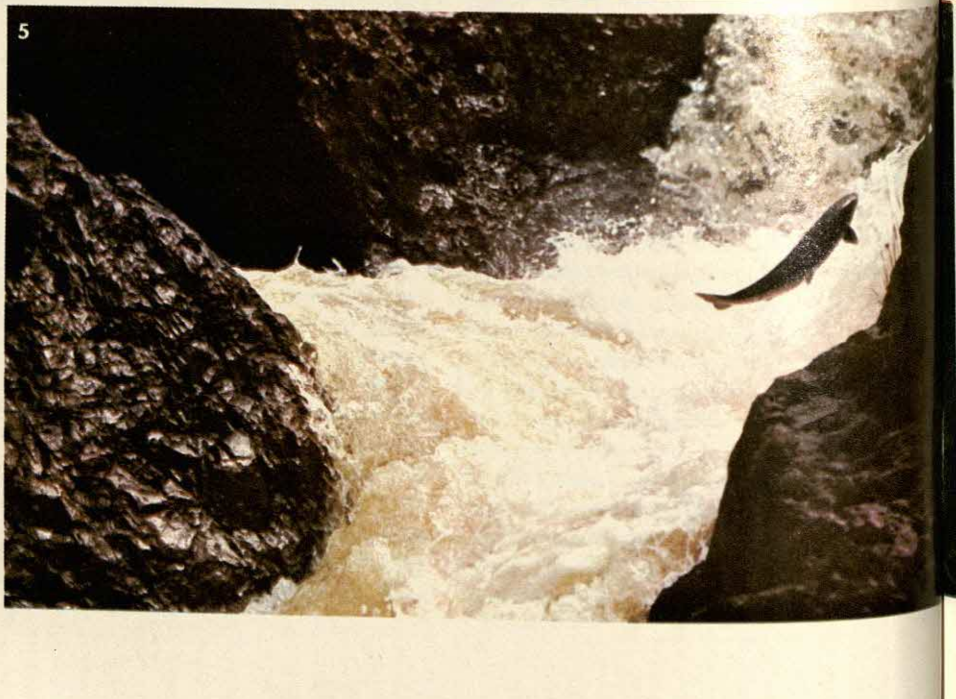

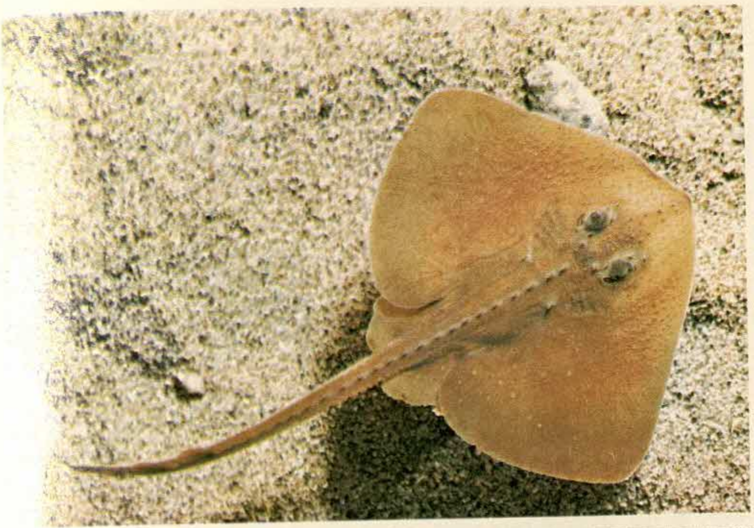

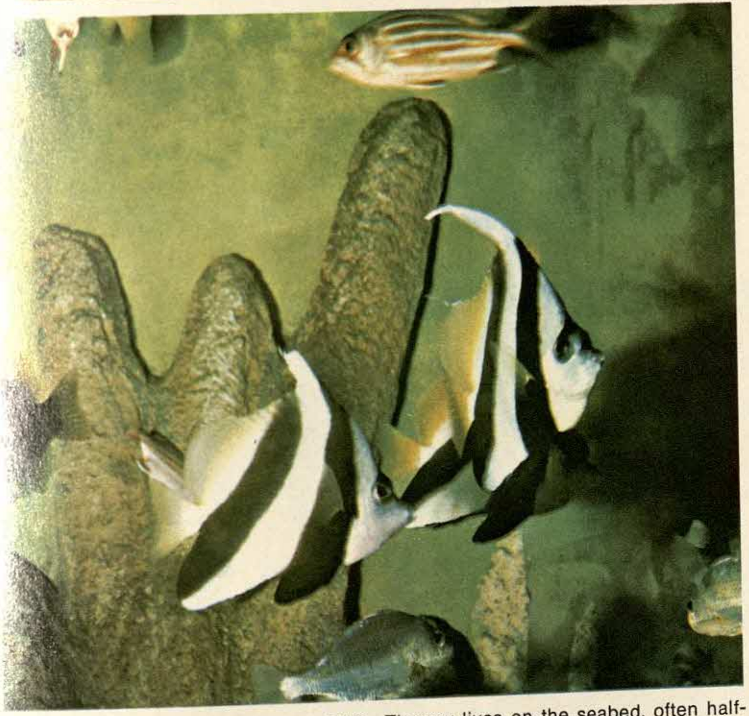

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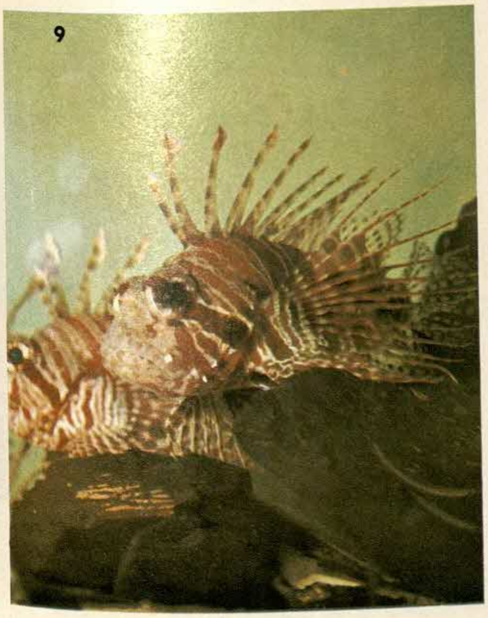


RAY—The ray lives on the seabed, often half-buried and almost invisible. Although its pectoral fins are very broad and strong, its caudal fin is undeveloped (Illustration 7).

BLACK AND YELLOW—These vividly colored fish are typical of tropical seas. Each has a crescent-shaped caudal fin (Illustration 8).

PTEROIS RUSSELLI—These fish have fins divided into narrow rays. The dorsal fins are rigid and pointed; the pectoral fins are long and brightly colored (Illustration 9).

A NEED FOR OXYGEN

Despite their streamlined shapes, fish can swim for only short periods because their muscles tire easily. The concentration of oxygen available to them is relatively low; breathing by gills, they must extract oxygen from water—but water does not hold as much oxygen as air. Because oxygen is used in respiration, the concentration of oxygen affects the amount of energy made available to muscles.

Dolphins often maintain speeds of 30 to 50 km (about 20 to 30 mi) per hour for several hours. But because they are mammals, they breathe with lungs; and because lungs absorb oxygen directly from the atmosphere, the muscle energy of dolphins is maintained at a high level.

THE FUNCTION OF THE LATERAL AND DORSAL FINS

A fish can change its direction rapidly without losing its balance. This is due to the stabilizing action of its dorsal and pelvic fins, the more posterior of the lateral fins. When a fish moves its tail to one side, the resistance of the water tends to rotate the fish's body in the opposite direction; the result, if the fish had no dorsal or pelvic fins, would be a zigzagging movement. The fins correct this effect by compensating with a movement in the opposite direction that reduces the tendency of the fish to stagger from one side to the other. The pectoral fins, which are the more anterior of the lateral fins, control the pitching movement that would otherwise cause the fish's head to rise and fall.

LOCOMOTION BY ROWING

The sea turtle's swimming apparatus, very different from the organs described above, consists of short, flat limbs that act as oars or paddles. When a rower pulls on his oar, the broad surface of the blade—at right angles to the surface of the water—exerts pressure against the water and pushes the boat forward. A turtle's limbs function in the same way.

In the Batoidei (deep-sea fish), the pectoral fins are the main organs of locomotion. Some fish rest on the seabed for long periods of time with their fins actually touching the floor of the sea as if to hold them up. The mudskipper occasionally ventures onto land in an attempt to capture insects and crustaceans.

SYMBIOSIS, PARASITISM, AND COMMENSALISM

living together

Plants and animals never live alone. During their lifetimes they interact not only with other members of their own species, but with other species. Not surprisingly, some of the hundreds of thousands of species inhabiting the Earth should have formed relationships in which members of two different and often unrelated species live together in a fairly intimate manner. Three types of such a relationship are symbiosis (mutual benefit to both species), parasitism (one-sided benefit), and commensalism (one-sided or mutual benefit).

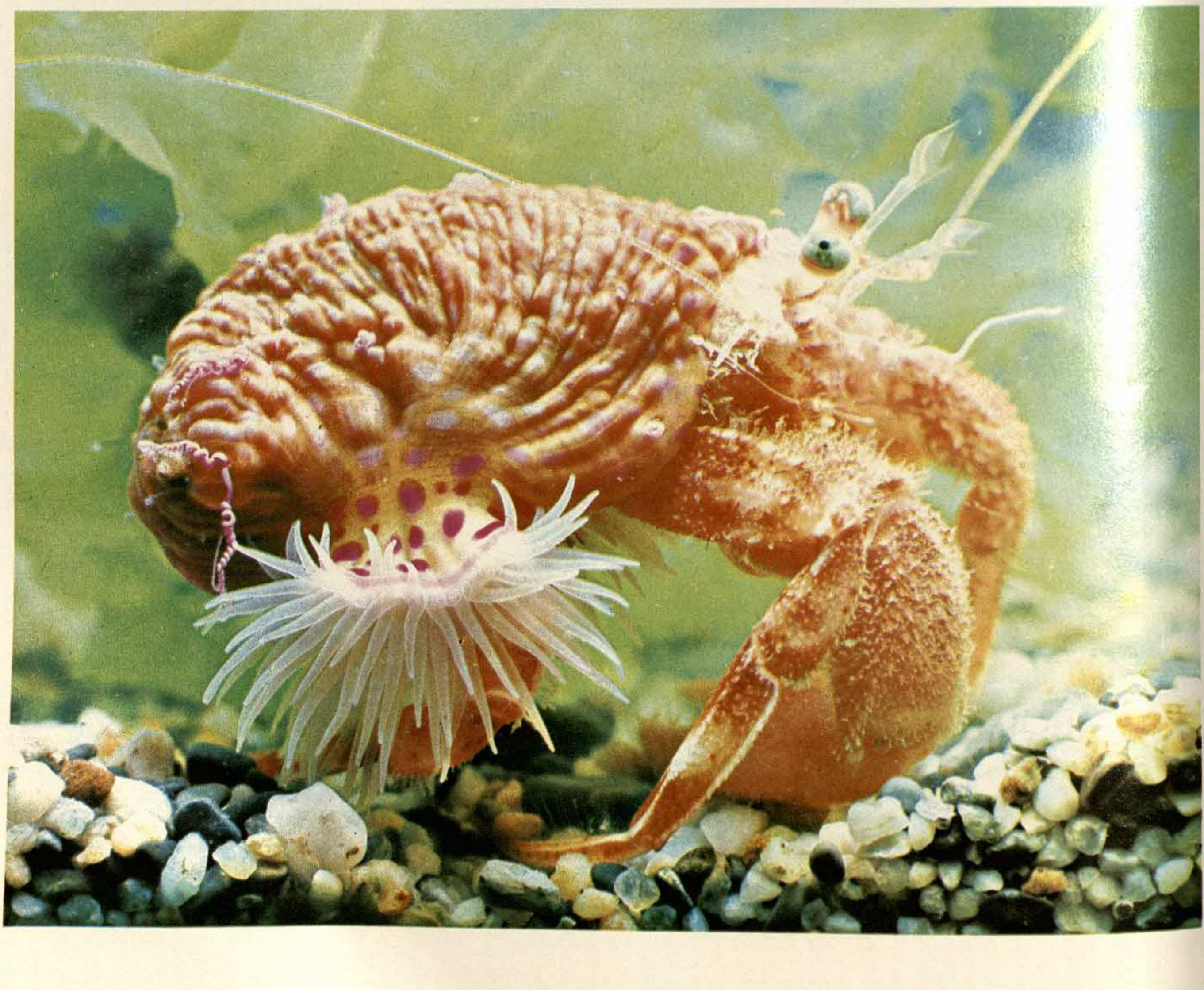
SYMBIOSIS

In a symbiotic relationship both partners benefit from the association. Sometimes the two partners are so dependent on each other that neither could survive without the other. The yucca plant, for example, is pollinated only by the yucca moth, which lays its eggs only in the ovary of the yucca flower. The larvae of the moth live exclusively on the seeds in the developing fruit. The plant would not be able to produce seed without the pollinating moth, and the moth larvae

1b

SYMBIOSIS BETWEEN A HERMIT CRAB AND A SEA ANEMONE (Actinia)—The hermit crab usually lives in the protection of an empty shell of a dead snail. One or more sea anemones may attach themselves to the shell (Illustrations 1a and 1b). A reciprocally beneficial association is established between the two animals. The sea anemone defends the hermit crab by means of its stinging cells, and its body hides the crab. The anemone, which would ordinarily remain fixed, is carried about by the crab, and eats its scraps.

1a



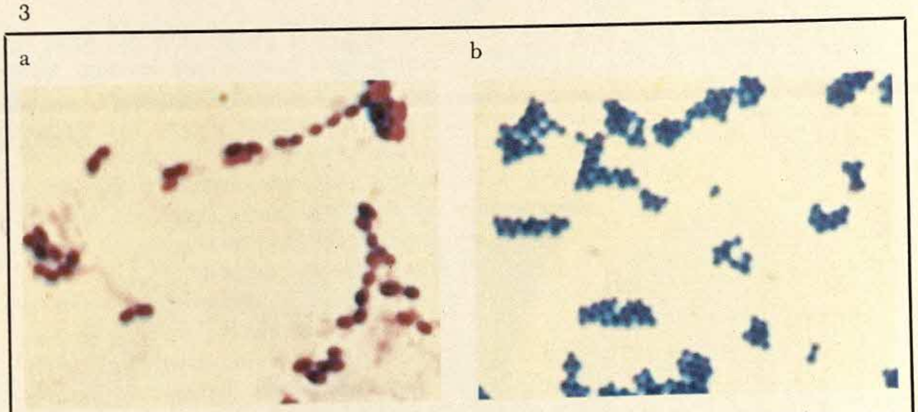
would die without yucca seeds to eat.

A lichen consists of a fungal and an algal component. The multicellular fungus, which lacks chlorophyll and cannot manufacture food, harbors unicellular algae in its tissues. The fungus receives food from the photosynthetic alga, which in turn receives water from the surrounding fungal tissues. Some lichens grow in exceedingly hot, cold, or dry habitats where neither of their components could survive alone.

Rhizobium is a genus of nitrogen-fixing bacteria that lives in nodules on the roots of beans, peas, and other legumes. The bacteria convert atmospheric nitrogen into nitrogen-containing organic compounds that the host plant utilizes. In turn, the host plant provides food, water, and minerals which the bacteria absorb.

Certain protozoa of the genus *Trichonympha* live in a symbiotic relationship in the intestines of termites. The termites have no enzymes with which to digest the cellulose in the wood they eat. The protozoa do have the necessary enzymes, however, and the food they digest is shared with the termite. The protozoa seem to receive some benefit, for they cannot survive outside their hosts.

3



INTESTINAL BACTERIA—These colon bacilli (Illustration 3a) and staphylococci (Illustration 3b) commonly live in a parasitic state in the human intestine. (2,000 X) Other important and useful symbiotic bacteria are those symbionts which inhabit the digestive organs of ruminants, digesting the cellulose-rich foods on which their hosts live.

MUSSEL ENEMY—This is a parasite commonly found in artificial mussel beds. The ropes on which the mussels are grown are raised and exposed to the air for several hours to kill these parasites.

2

PARASITISM

Parasitism is a relationship in which one organism lives at the expense of another. The parasite receives all the benefits from this association, while the host is sometimes harmed to a greater or lesser degree. Many parasites draw nourishment from their hosts without killing them. This is beneficial for the parasite, for it will usually die if deprived of a live or healthy host. Nonetheless, a few parasites do kill their hosts.

Some parasites are pathogens; that is, they cause disease. Some of the diseases caused by fungal parasites are athlete's foot, ringworm, Dutch elm disease, and wheat rust. Typhoid fever, pneumonia, cholera, and diphtheria are only a few of the diseases caused by bacteria. Malaria, amebic dysentery, and African sleeping sickness are caused by protozoa. Viruses cause smallpox, measles, poliomyelitis, influenza, and the common cold. One type of virus, the bacteriophage, parasitizes bacteria.

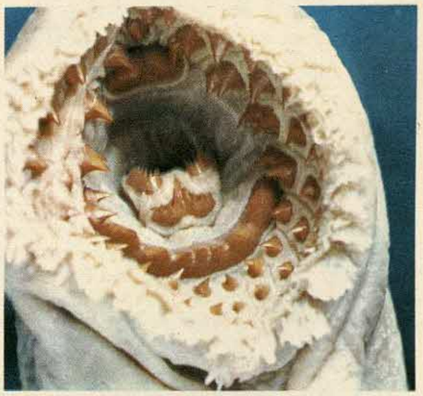
Parasitism is widespread in both the plant and animal kingdoms. Nearly every species is parasitized by at least one other. A flea on a dog, for example, sucks the dog's blood but is in turn the host of mites that suck its lymph. Fungi live on the mites as well as certain bacteria that are attacked by viruses.

The parasitic life usually is accompanied by several modifications. The legs of some parasitic insects become simple claws with which they attach themselves firmly to their host. The mouths of some parasitic worms have suckers by which they fasten themselves to and take nourishment from the host. Other adaptations include flattening of the body in a horizontal plane if, like bedbugs and lice, the parasites adhere to smooth surfaces such as the skin, or in a vertical plane if, like fleas, they live and move among hairs. Parasites usually have no digestive system or only a reduced one, for they absorb digested food from their hosts.

If a parasite does not have to search for food, the organs of locomotion may be very much reduced. However, parasites often have special means of transferring eggs, larvae, or other stages of the life cycle to a new host. Some of them, like the Chinese liver fluke and the malaria organism, have complex life cycles in which an alternate host or hosts transfer the appropriate stage to the new host. To pass from one human to another the Chinese liver fluke must spend part of its life cycle in snails and another part in fish. The malaria organism is transferred by the bite of the *Anopheles* mosquito. Parasites often have well-devel-

LAMPREY'S MOUTH—The mouth is surrounded by a sucker furnished with soft papillae and strong horny teeth. This parasitic animal attaches itself to the bodies of certain kinds of fishes by means of this sucker, shredding the fish's tissues and sucking its blood.

4



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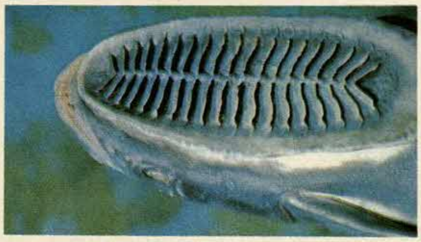


THE REMORA—On the dorsal surface of the remora's head is an adhesive disk with transverse furrows. By means of this structure the remora firmly attaches itself to the sides or bellies of whales, large fish, or turtles. Thus it is carried to where it can feed on the remains of the food that its host animal eats. It is very common to see groups of remoras on the flanks of sharks.

oped reproductive systems and produce great numbers of offspring; but only a few ever reach a suitable host.

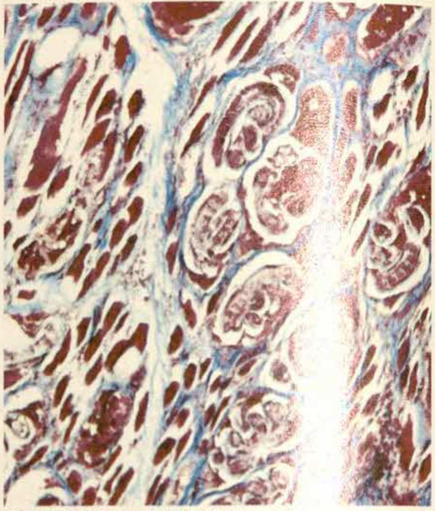
COMMENSALISM

In commensalism, one of the partners in the association benefits from the relationship while the other may or may not be benefited. Remora fish attach themselves to sharks, whales, or other large marine animals. Their weight does not seem to bother their host, whose leavings they eat. Orchids and other epiphytes (plants that grow on other plants) live on tree branches where they can receive more sunlight than they would if they grew on the forest floor. Epiphytes take no nourishment from their hosts but merely utilize them as supports.

The types of dependence shown in commensalism involve shelter, support, food, and locomotion–singly or in combination. Remoras derive both locomotion and food; epiphytes, support alone. An example of the shelter relation is seen in the *Nomeus* fishes that live among the tentacles under Portuguese men-of-war. Bacteria and protozoa that live in the digestive tract of larger animals illustrate commensalism in which food supply is the main factor.

It is not always easy to distinguish clearly between symbiosis, parasitism, and commensalism, for many intermediate relationships exist. Some parasites receive so little food from their hosts and do so little damage that they are more like commensals than parasites. In some lichens the alga receives no known benefit, and so the relationship may approach parasitism. Epiphytes, if present in great numbers, may harm the host tree by depriving it of the sunshine it requires.

6



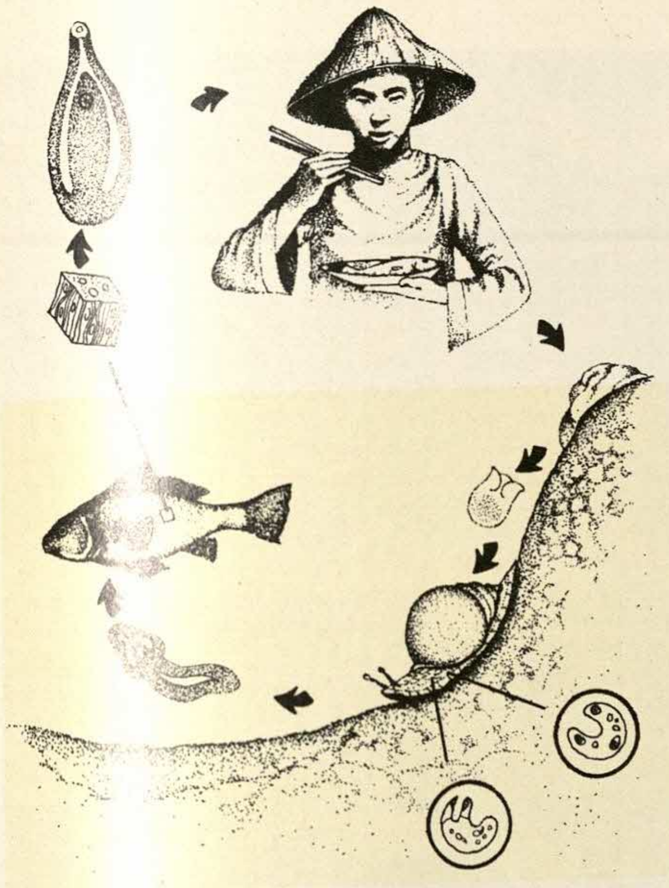
TRICHINELLA SPIRALIS—This pathogenic parasite can be ingested by eating raw or improperly cooked pork. The larvae pass from the intestine into the muscles, where they form the spiral cysts shown in this illustration.

7a

7b

MISTLETOE—This parasitic plant (Illustrations 7a and 7b) occurs in large bunches on branches of many species of trees. Its roots penetrate the wood from which it absorbs water and minerals. It is not, however, completely parasitic, for it contains chlorophyll and therefore can carry on its own photosynthesis. Mistletoe flowers in spring or summer. The flowers are yellow; the fruits are smooth, white berries with a viscous pulp.

8a



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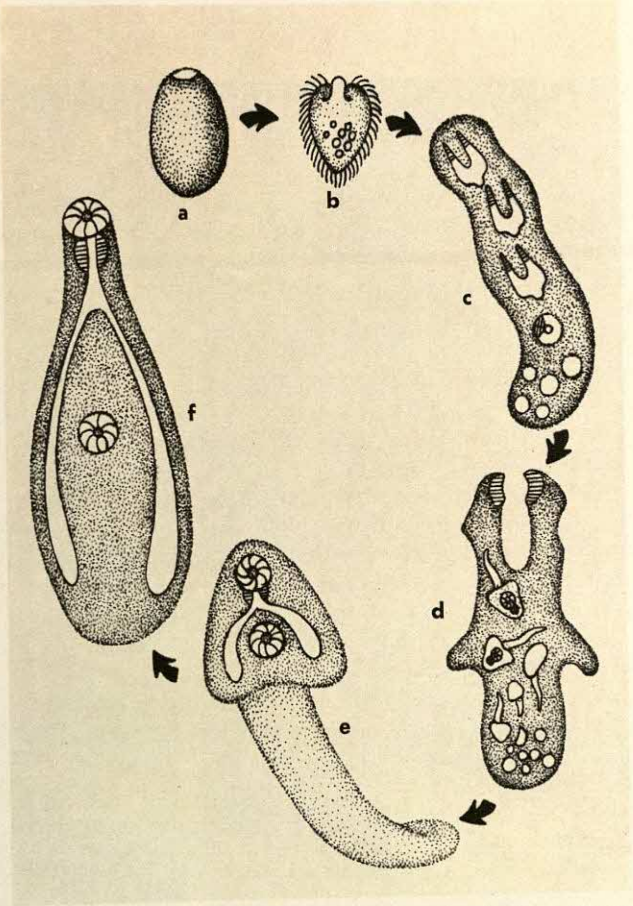
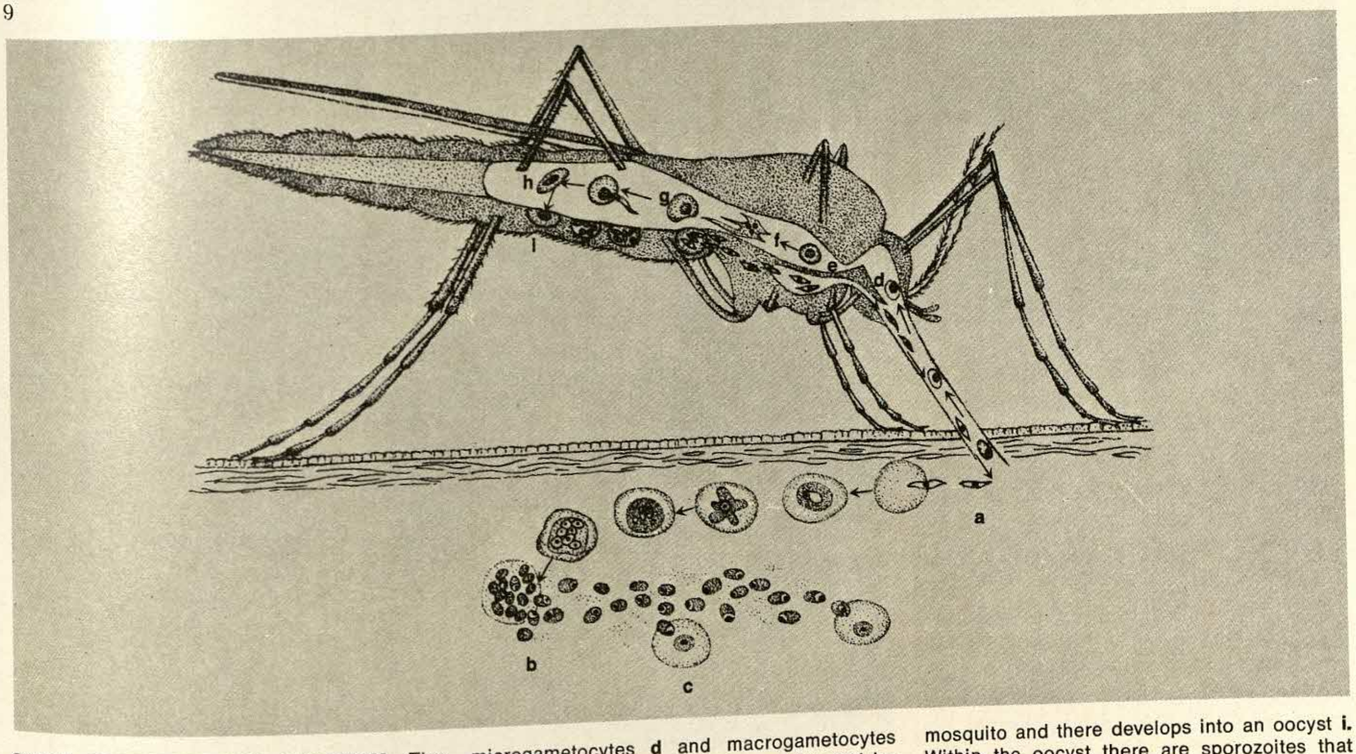


CHINESE LIVER FLUKE—This pathogenic parasite (*Clonorchis sinensis*) of the human liver is widespread in the Orient. Its life cycle is represented in Illustration 8a. The egg is liberated in water and is eaten by a snail. The egg hatches into a miracidium that reproduces itself, forming rediae and then cercariae. The latter infects fish. In man, who is infected by eating raw fish, the parasite develops into an adult. Illustration 8b shows egg **a,** miracidium **b,** sporocyst **c** with rediae, redia **d** with cercaria, cercaria **e,** and adult **f.**

9



CYCLE OF THE MALARIA ORGANISM—The *Anopheles* mosquito bites man, injecting him with sporozoites **a** that eventually enter red blood cells. Each sporozoite divides into many merozoites **b,** which may reinfect red blood cells **c.** Merozoites instead may develop into microgametocytes **d** and macrogametocytes **e** that enter a mosquito biting an infected individual. In the stomach of the mosquito these cells mature into microgametes **f** and macrogametes **g** that fuse, giving rise to a zygote **h** that passes through the stomach wall of the mosquito and there develops into an oocyst **i.** Within the oocyst there are sporozoites that form and then pass into the salivary glands from which they pass into the next person bitten. It is believed that malaria is probably the world's most widespread infection.

SPIDERWEBS | nature's artistry in silk

Nearly everyone can recognize spiders on sight—and many have been frightened by them—but few laymen have any real knowledge of their structure and habits of life. This may be due to the fact that spiders are commonly regarded with fear and are believed, quite wrongly, to cause serious damage. Although some spiders can puncture a man's skin with their sharp chelicerae (appendages located near the mouth and terminating in fangs supplied with a poison gland), few spiders are poisonous to man or other large animals. Even the dreaded tarantula (*Lycosa tarentula*) is relatively harmless and does not deserve its fearsome reputation. Black widow spiders (several species of *Latrodectus*), however, inflict extremely painful bites that may be accompanied by nausea, respiratory difficulties, and muscle spasms. Adults usually recover, but black widow bites have been fatal for small children. The brown recluse spider (*Loxosceles reclusus*) of the United States and the Brazilian wolf spider (*Lycosa raptoria*) cause the formation of sores that are slow to heal.

SECRETING THE SILK THREAD

One of the most interesting things about spiders is their ability to produce silk, which they manufacture in abdominal glands. The silk is secreted through two or three (rarely one or four) pairs of spinnerets near the posterior of the abdomen. Each spinneret consists of several hundred minute spinning tubes. The streams of liquid silk excreted by one or more pairs of spinnerets harden immediately upon leaving the spinnerets and join together in a single thread. Hardening of the silk is due to the drawing-out process and not to exposure to the air.

Spider silk may have a variety of properties according to its function. It may be dry and inelastic, or sticky and elastic; its diameter may vary between 0.005 and 0.03 mm (about .0002 to 0.0012 in.), and it may take the form of a thin ribbon. Many webs and egg sacs and the draglines produced by spiders whenever they travel are dry threads. Sticky threads are used primarily in those webs that serve as traps for prey. Seven kinds of silk glands have been discovered, each producing a different kind of silk. Most spiders have four or five kinds of silk glands.

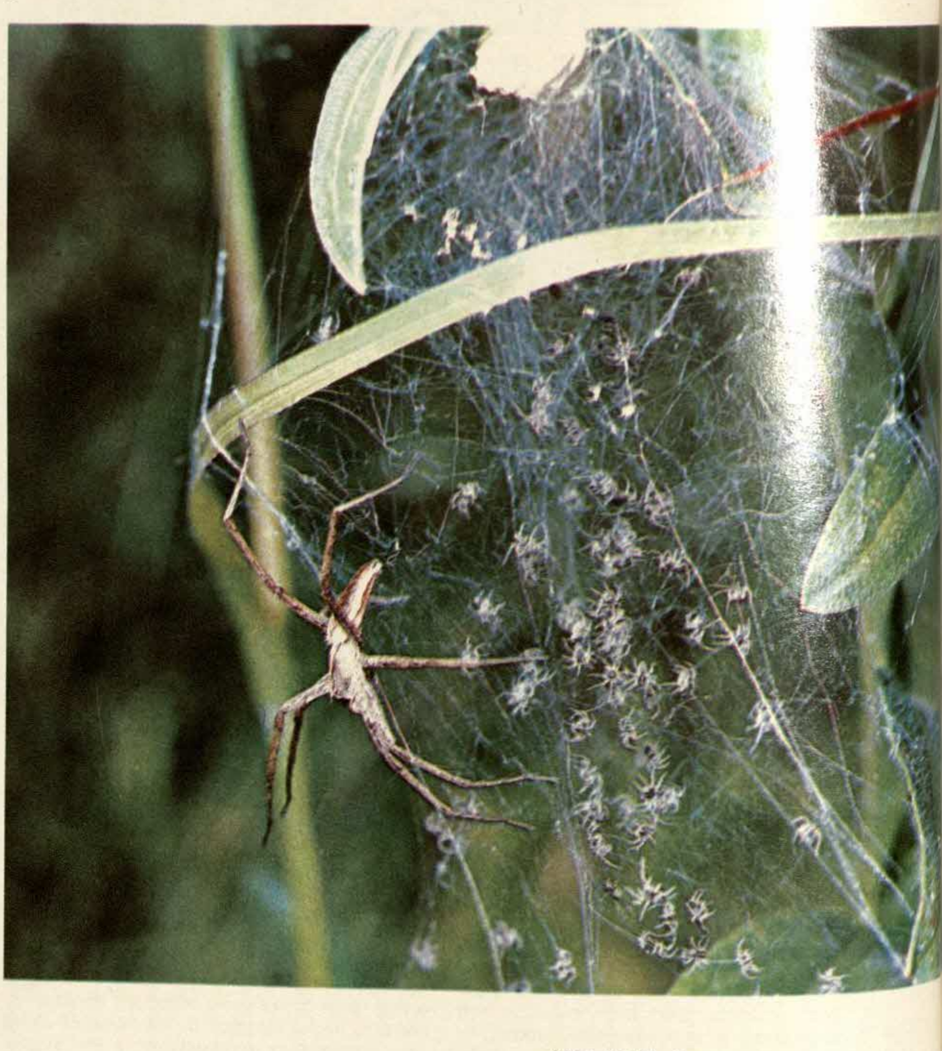
The back legs of a spider are equipped with various claws and hooks. The spider uses these to guide the thread as it comes out of the spinnerets, holding it taut or attaching it to other threads or to a support. If the thread is sticky, the spider avoids becoming entangled in it by holding it away from the body. The technique, while amazing in complexity, is wholly instinctual.

TYPES OF THREADS

Draglines, attachment disks, swathing bands, swathing films, viscid threads, hackled bands, and egg-sac silk are different types of spider silk. Everyone at some time or other has seen a spider descending from a ceiling or branch on a thin thread. The spider manufactures its own elevator by secreting a dragline as he goes along, and he can easily climb up it if necessary. Draglines are used not only as lines of retreat but also to bridge an empty space. The spider lets the dragline float in the air until a passing breeze catches it and carries it onto the nearest

WEBS TO LIVE IN—A female wolf spider stands guard over its web and newly hatched young. This species uses the web as a nest. Certain other species use holes in walls or the ground; these they line with silk threads.

1



A DELICATE NETWORK OF SILVER THREADS —Drops of dew on the threads lend clarity to this spiderweb. The symmetry of some webs approaches perfection. Nearly every species of spider has special building techniques, and the design remains the same throughout the lifetime of the individual spider. Without benefit of intelligence, spiders accomplish their intricate tasks by instinct.

support. The spider then attaches its end of the thread to the original support by an attachment disk and travels along the slender bridge.

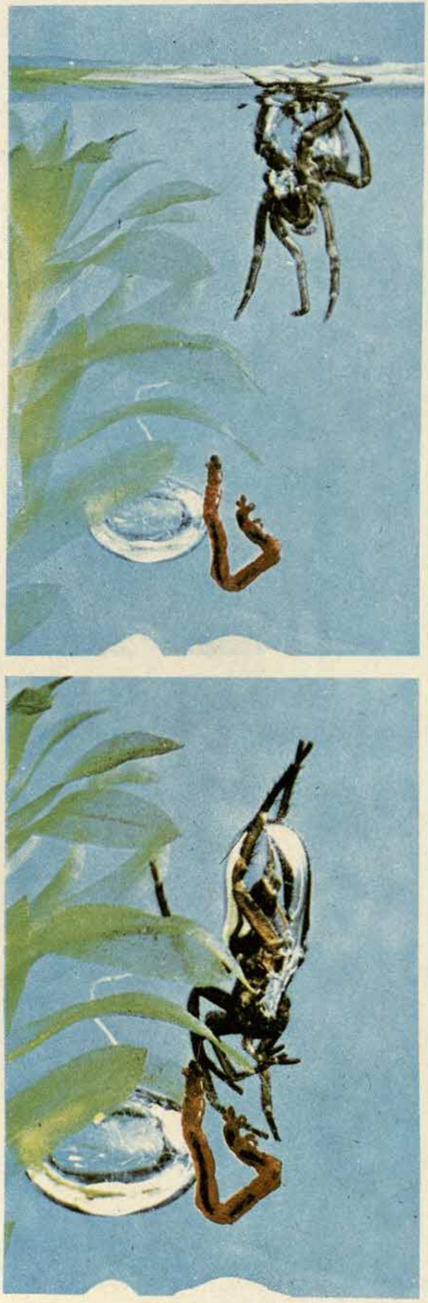
Small spiders sometimes "balloon"—that is, secrete a dragline that is wafted upward by the wind. As soon as this rudimentary flying machine is large enough to bear its weight, the spider launches its support and takes to the air. Sometimes it is carried for several miles.

Swathing bands and swathing films are spun around prey, which thus is immobilized in a cocoonlike structure. Viscid threads are sticky threads with a similar function, but they usually are part of the web. When an insect becomes attached to a viscid thread, its struggles only serve to entangle it further.

Hackled bands appear to be fine threads, but when magnified they are more like flat bands consisting of several long parallel threads resting on a narrow ribbon.

3

a



b

WATER SPIDERS—The water spider spins its nest under water. It fills the nest with large air bubbles that it carries down from the surface. When enough air has accumulated, the spider thickens its web and shapes it into a kind of air-filled diving bell in which it can live.

Silk to be used in egg sacs is produced in special glands found only in female spiders. It is dry and variously colored.

SPIDER SILK

Spider silk is a protein known as fibroin. Chemically, it resembles the center core of the commercial silk produced by silk moths, but it lacks the outer sheath of the protein sericin. The exact nature of the silk varies with the species of spider and also with the particular glands from which it is produced.

Strong and elastic, the silk can be used to make excellent textiles, but it is too expensive to be produced commercially. It has been used for cross hairs in telescopes, gunsights, and other optical instruments, but it has been replaced to a great extent by engraved glass and platinum filaments.

WEBS AS TRAPS AND WEBS TO LIVE IN

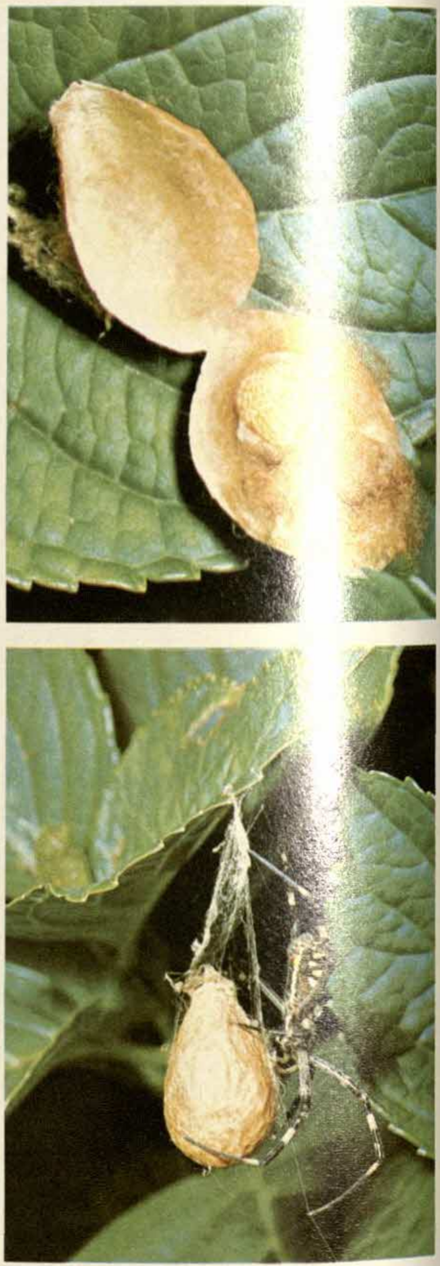
Watching a spider work (the females are usually the best craftsmen) is a rewarding occupation. Almost every species of spider has its own building techniques, and each individual of the species follows the same blueprint. Individuals do introduce some variations, however, as local conditions demand; and individuals become more skillful with practice.

A difference between webs used as traps and webs used to live in does exist, but many spiders actually live in the traps they make and many others build a traplike construction around their nests. Trapper webs may or may not be symmetrical in structure. Asymmetrical trapper webs are made of threads woven haphazardly in every direction and sometimes may be thick enough to be indistinguishable from fabric, looking rather like a piece of cloth anchored to adjacent supports. Examples of this type of web are the well-known triangular webs made by the genus *Tegenaria* in the corners of houses and cellars, and the white, funnel-shaped, clothlike webs spread over grass

4

COCOONS OF THE GENUS *ARGIOPE*—The females of this genus use the finest silk to construct variously shaped and variously colored cocoons in which they house their eggs. A cocoon cut in half (Illustration 4a) displays the patient work done by the spider to protect its offspring. In Illustration 4b, a female hangs the cocoon, full of eggs, from a leaf.

a



b

and bushes by the genus *Agalena*.

Symmetrical webs include those woven by the common orb weavers (several species of the genus *Aranea*). The spider (usually the female) constructs a bridge by throwing a dragline. From the center of the bridge she drops a vertical line to the ground. The point from which the vertical line is dropped will become the center of the web. The spider then constructs several more lines that radiate from this point. These spokes are evenly spaced, and the number of spokes is usually constant for each species. This done, the spider starts weaving a temporary spiral that becomes the scaffolding for her eventual trap; she begins near the center and lays down a dry, spiral thread. When she reaches the edge of the web, she turns around and retraces her steps from the outer rim toward the center; this time she secretes sticky thread that she fixes to the spokes. The temporary spiral is removed and discarded as she goes along. When the web is finished, the spider may install itself at the center and wait for prey to become entrapped. She may stand watch in the surrounding foliage, keeping contact with the web by means of a special thread that vibrates when a victim is caught. A large orb weaver may use 1 to 3.5 km (about 0.6 to 2.2 mi) of thread in a month to build or repair her web.

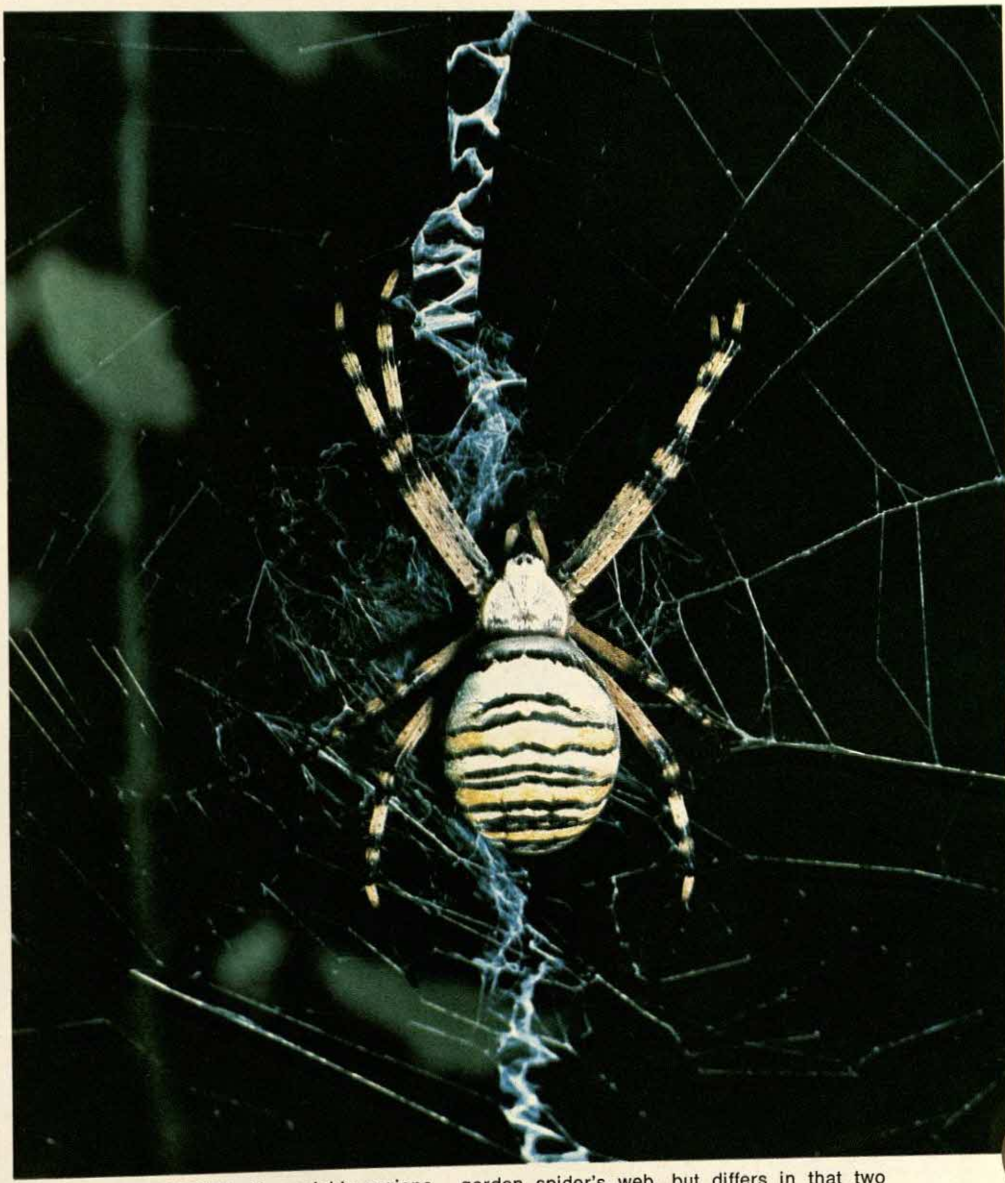
Other kinds of webs are built by spiders to protect themselves from unfavorable conditions or to raise their offspring. The most curious example is the web of the water spider, *Argyoneta aquatica*. The spider first constructs a thick network of threads as it swims among the underwater weeds of ponds and brooks; it then carries bubbles of air down to the web. When it has accumulated enough air, it thickens the fabric of its web and shapes it into a kind of diving bell in which it lives.

Hundreds of spiders use their silk to make their nests safer and more comfortable. The genera *Filistata* and *Segestria*, for example, live in holes in walls or banks that they line with threads and silky fabric. The tarantula and other spiders of the genus *Lycosa* dig cylindrical burrows in the ground and carpet them with delicate webs, the entrance being protected by a covering of mold and surrounded by a turret of sticks or stones.

Several spiders, including *Dictyna civica* and species of *Tegenaria*, live almost exclusively in human dwelling places.

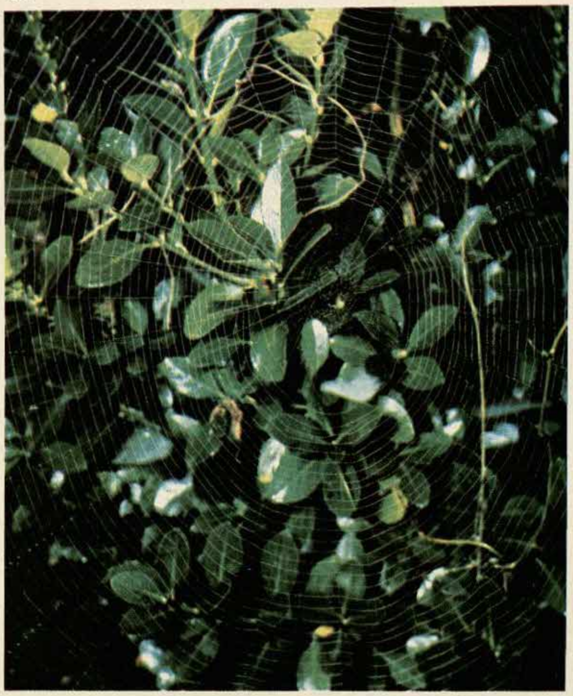
Country spiders include the genus *Agalena*, found in meadows and bushes; a bright green member of the genus *Dictyna* that weaves its web in the hollows of leaves where its color makes it almost invisible; and the spiders of the genus *Clubiona*, which nest in tree bark, under stones, or in rolled leaves.

5

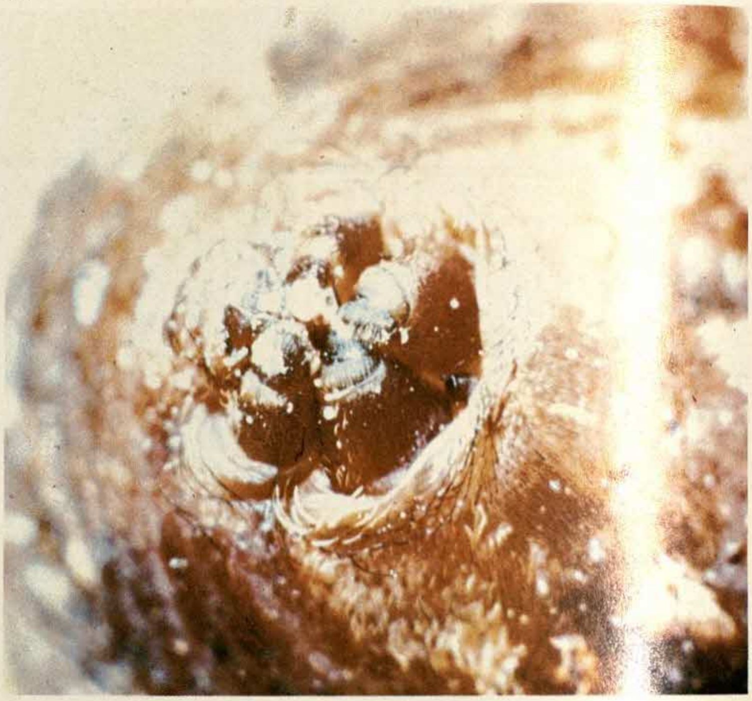


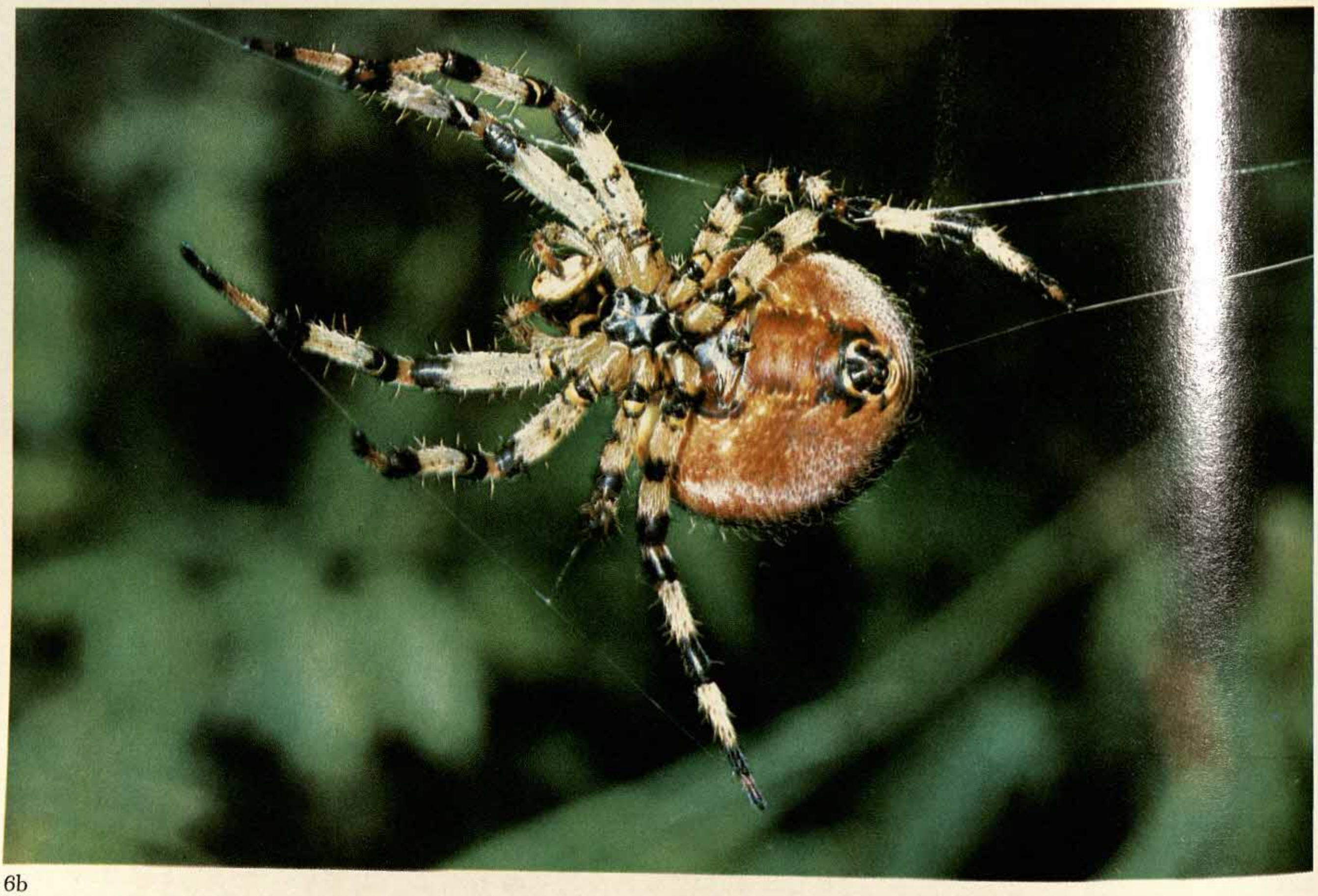
ARGIOPE BRUENNICHI—Bruennich's argiope is a common European spider. It has striped legs and a light-colored abdomen with characteristic dark stripes. Its web resembles the garden spider's web, but differs in that two ribbon-shaped strips cross it in a zigzag pattern.

6a



6c





6b

SPIDERWEBS USED AS TRAPS—The highly symmetrical web (*Illustration* 6a) of the orb weaver spiders so common in gardens is used to trap victims. Illustration 6b shows a spider weaving its web. The spider first attaches the threads to several supports to form the frame in which it constructs several spokes of threads. It then uses sticky threads to build the characteristic spiral of the web. Illustration 6c is a closeup of the spinnerets, which are also visible in the previous photograph. Special glands located at the rear of the spider's body secrete the liquid silk through the spinnerets. The silk hardens into a thread as it leaves the spinnerets.

EPITHELIAL TISSUE | the protective shield of the organism

The entire surface of our body is covered by a thin layer of tissue known as the epithelium, which also covers most organs of the body and lines most body cavities. Because the epithelium performs different functions in different areas, it consists of several types of cells arranged in several ways.

The epithelium that covers the external surface of the body protects it from drying out and from abrasion. Epithelia within the body are smooth and allow the internal organs to move easily over each other without abrasion. Materials entering or leaving these organs must pass through the epithelia, which are modified as necessary for absorption or secretion. Some single epithelial cells act as unicellular glands, and multicellular glands are formed by the invaginations of some epithelia.

One surface of an epithelium is called the free surface, which is the one exposed to the air (in the case of the skin) or body openings, cavities, and passageways (in the case of internal epithelia). The opposite surface of the epithelium rests on connective tissue. In some cases a thin basement membrane lies between the epithelium and connective tissues; the basement membrane itself is considered a modification of connective tissue.

Most epithelia of the body are not supplied with blood vessels, and they receive their food by way of the underlying connective tissue, which is served by the circulatory system. Although some internal epithelial tissues lack nerve endings, others, like the nasal epithelium and the skin, have sensory nerve endings.

CLASSIFICATION OF EPITHELIA

Epithelia are classified on the basis of the shapes of the cells of which they are composed and the number of cell layers in the tissue. Epithelial cells have three basic shapes: squamous, cuboidal, and columnar. Squamous cells are obviously flat; cuboidal cells are nearly uniform in diameter; and columnar cells are tall, prismatic cells. All intermediate shapes exist. Low cuboidal cells resemble squamous cells, while high cuboidal cells cannot be distinguished from low columnar cells.

Simple epithelium is composed of one layer of cells, and stratified epithelium has two or more layers. Pseudostratified epithelium is a simple epithelium, but the arrangement of the nuclei in the cells gives the tissue a stratified appearance.

Transitional epithelium is stratified epithelium in which the number of cell layers and the shapes of the cells change as the tissue stretches or relaxes.

CILIA AND MICROVILLI

The free surfaces of some epithelial cells bear cilia or microvilli. Cilia are short, hairlike projections. By bending back and forth rapidly in whiplike motions they create currents that can move small objects. The action of ciliated epithelia keeps passageways of the respiratory tract clean; in the female reproductive tract they move the egg from the ovary to the uterus.

Microvilli are minute fingerlike projections on the free surfaces of epithelia in the intestine and in the tubules of the kidney. They are uniform in size and stand in close, regular arrangement. Seen under a light microscope, they resemble the bristles in a brush and together are known as the brush (or striated) order. Microvilli occur primarily in epithelia whose function is absorption, and they greatly increase the absorbing surface. They are so densely packed in the small intestine that they look velvety.

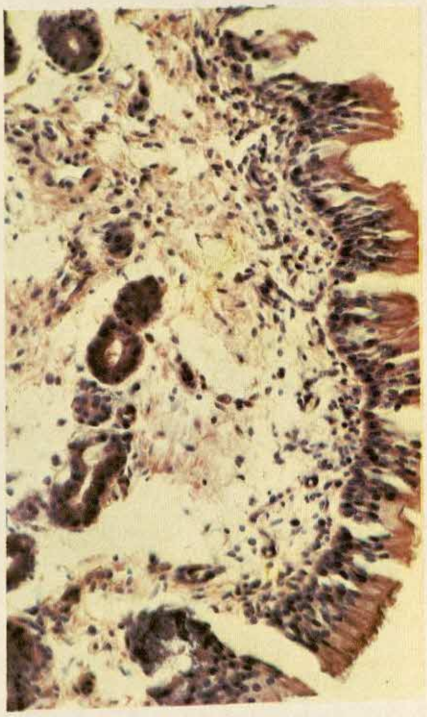
SIMPLE EPITHELIA

Simple squamous epithelium consists of a single layer of squamous cells. On the surface the cells appear to be hexagonal, and they fit together tightly without any spaces between them. The cells may have regular or wavy outlines. Simple squamous epithelia line the heart and blood vessels; the pericardial cavity, which surrounds the heart; the pleural cavity, which is the chest cavity; and the peritoneal cavity, which holds the several abdominal organs.

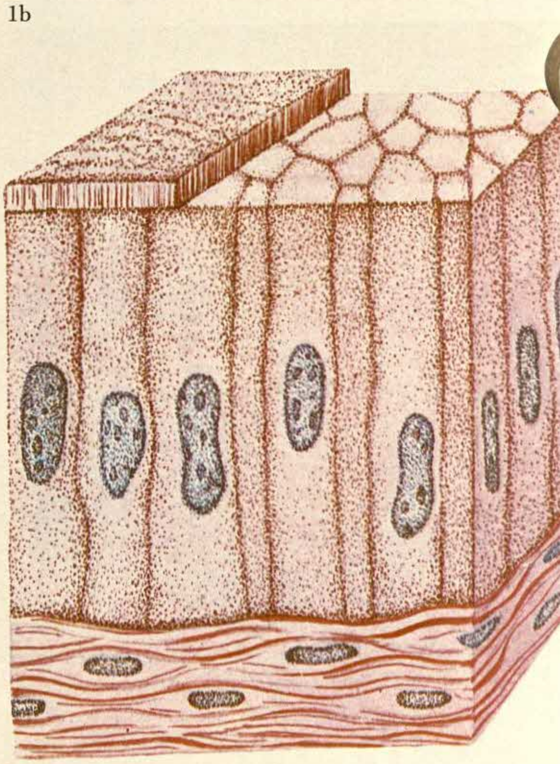
Simple cuboidal epithelium has a single layer of cuboidal cells packed closely together. Like simple squamous epithelium, it displays a hexagonal pattern on its surface; it is found in kidney tubules, the inner surface of the lens of the eye, the surface of the ovary, and several glands, including the thyroid gland.

Simple columnar epithelium, which is a single layer of columnar cells, lines the intestinal tract, part of the stomach, and the ducts of associated glands. The columnar epithelia of the respiratory tract, the uterus, and the oviducts have cilia on their free surfaces. The action of the cilia in the respiratory tract moves mucus,

1a

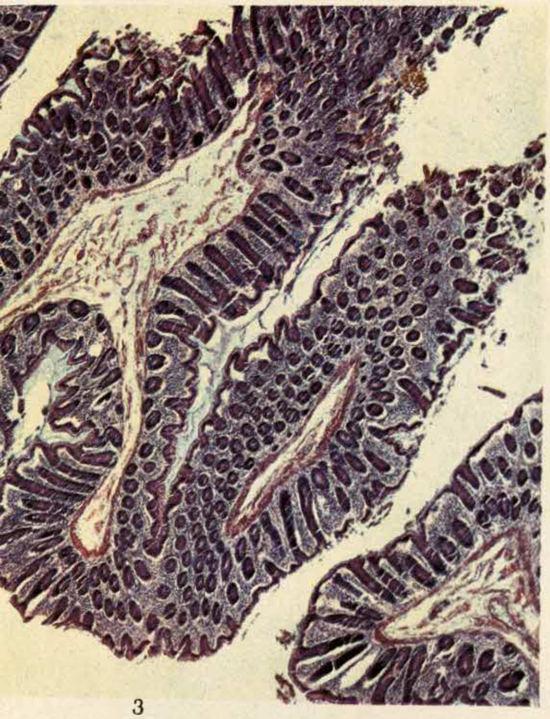


1b



SIMPLE COLUMNAR EPITHELIA—Illustration 1a is a photomicrograph of nasal mucosa. (250 X) Illustration 1b is a three-dimensional reconstruction of simple ciliated columnar epithelium; underlying the epithelium is connective tissue.

2



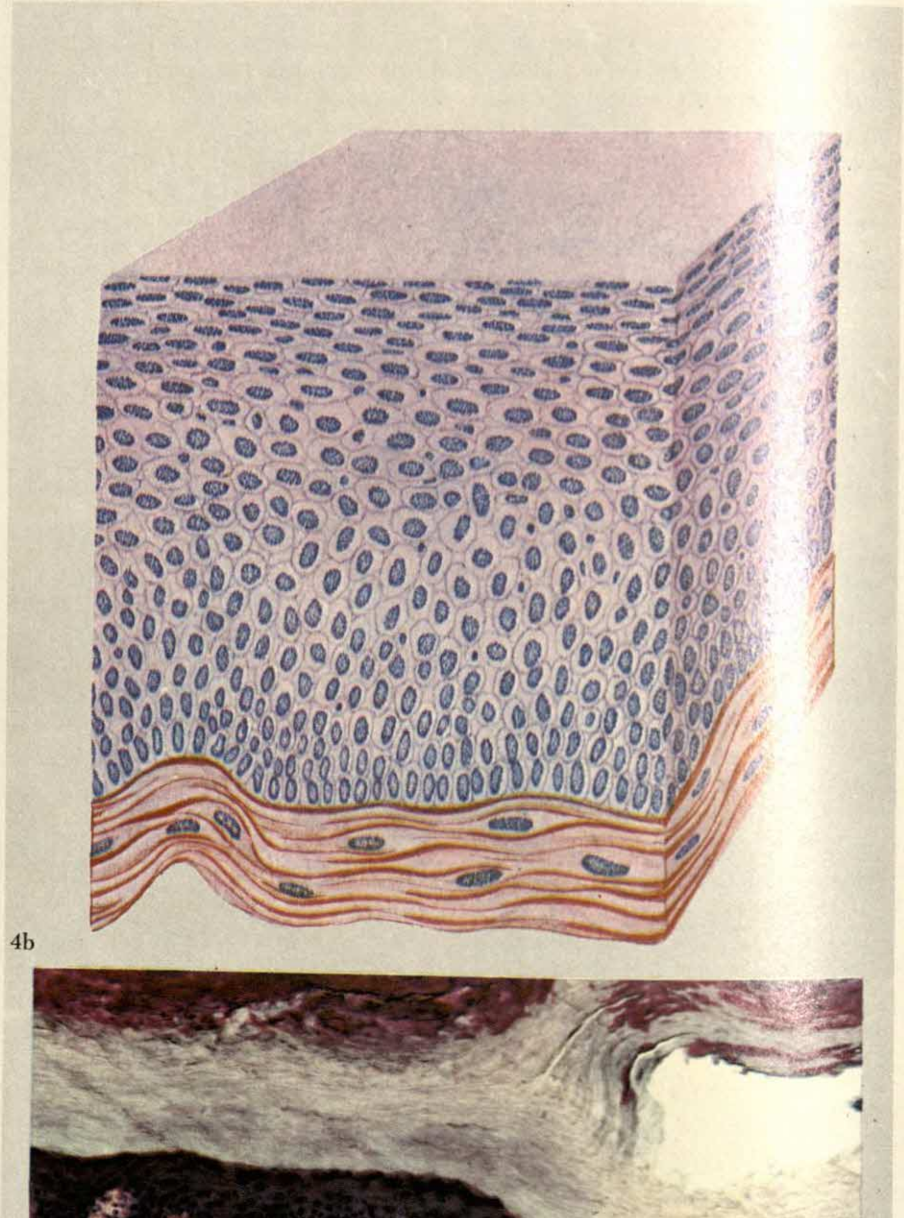
3

STOMACH MUCOSA—The mucosa of the stomach is lined with simple columnar epithelium. (110 X)

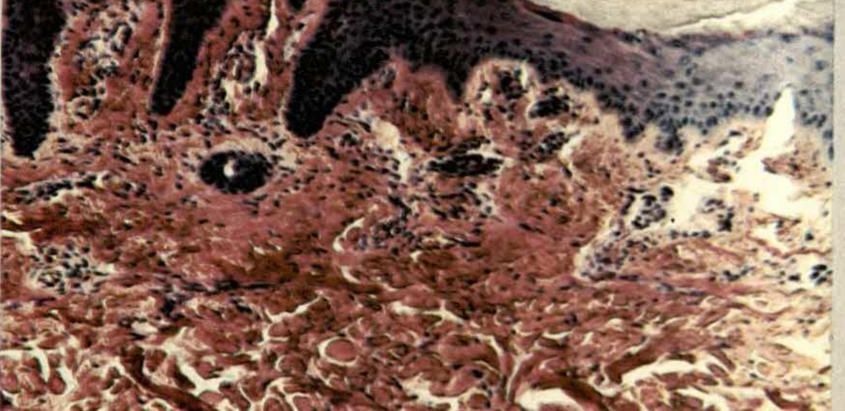
EPITHELIUM OF THE ESOPHAGUS—The epithelium that lines the esophagus, the mouth, and the outer surface of the body is stratified squamous epithelium made up of several layers of cells. (80 X)

STRATIFIED SQUAMOUS EPITHELIUM—Illustration 4a shows the outermost layers, which consist of flat, squamous cells and the cuboidal lower cells. Connective tissue underlies the epithelium. The stratified squamous epithelium of the skin (Illustration 4b) produces keratin, a light, nonliving, horny portion that flakes off. (100 X)

4a



4b



bearing bacteria and other foreign material, upward to where it can be expelled from the body by sneezing or coughing. The cilia of the female reproductive tract draw the egg just released by the ovary into the oviduct where fertilization occurs. They also conduct the fertilized egg to the uterus where it is implanted in the uterine wall.

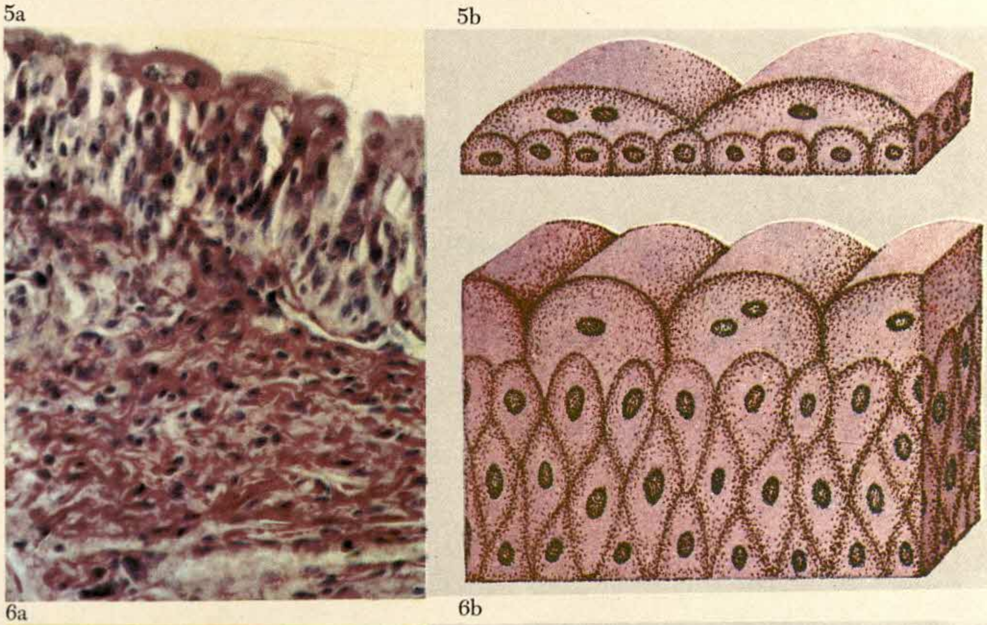
Pseudostratified epithelium has cells of several shapes. Some are columnar, and between them are smaller cells of irregular shapes. These cells all comprise a single layer of tissue, but because the nuclei of different cells lie at different distances from the basement membrane, and because the cells are of different sizes, the tissue has the appearance of being stratified. This tissue occurs in the respiratory tract, in the ducts of several glands, and in the male urethra.

STRATIFIED EPITHELIA

Stratified squamous epithelia consist of several layers of cells. Those on the free surface are squamous cells, while those below are cuboidal or columnar. The epidermis of the skin is stratified squamous epithelium that protects the entire outer body surface. The cells on the free surface are dead and contain the protein keratin. These cells slough off in small scales and are replaced by living cells from deeper layers. Stratified squamous epithelium also lines several of the body openings; among them are the mouth, esophagus, vagina, and female urethra. Here the cells are moist and not keratinized. Fewer cells form the moist stratified epithelium than the dry skin.

Stratified cuboidal epithelium, with a few layers of cuboidal cells, is found in sweat glands, sebaceous glands, and seminiferous tubules of the testis. Stratified columnar epithelium has several layers of cells, those at the free surface being columnar (the underlying cells may be of various shapes). This tissue is found in parts of the male urethra, excretory ducts of some large glands, and some parts of the respiratory system.

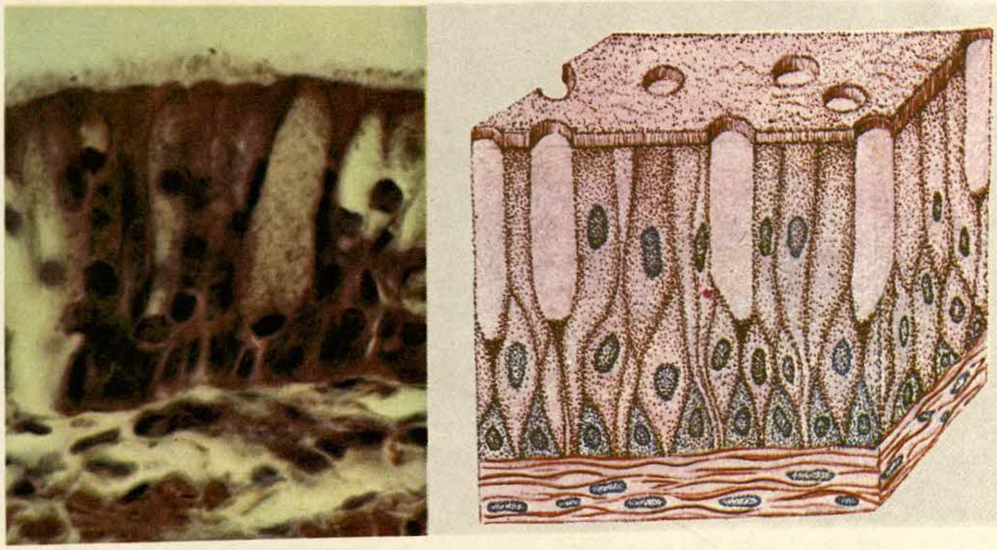
Transitional epithelium is a stratified epithelium that lines the urinary bladder, the ureters, and parts of the urethra and kidneys. The free surface of the outer cells is convex; the inner cells are cuboidal or columnar. This tissue has the ability to stretch and contract. In the contracted state the tissue is five or six cell layers thick; when it stretches, the cells change their shapes and special relationships to each other, and the tissue may become only two or three cells thick. When it relaxes, it assumes its former organization.



5a

5b

SECTION OF THE URINARY BLADDER—Transitional epithelium (Illustration 5a) has a layer of dome-shaped cells above irregularly shaped cells. (625 X) It is capable of expanding and relaxing. The upper part of Illustration 5b shows transitional epithelium in the distended phase; the lower part shows it in a relaxed phase. In the distended phase, the cells are stretched transversely.



6a

6b

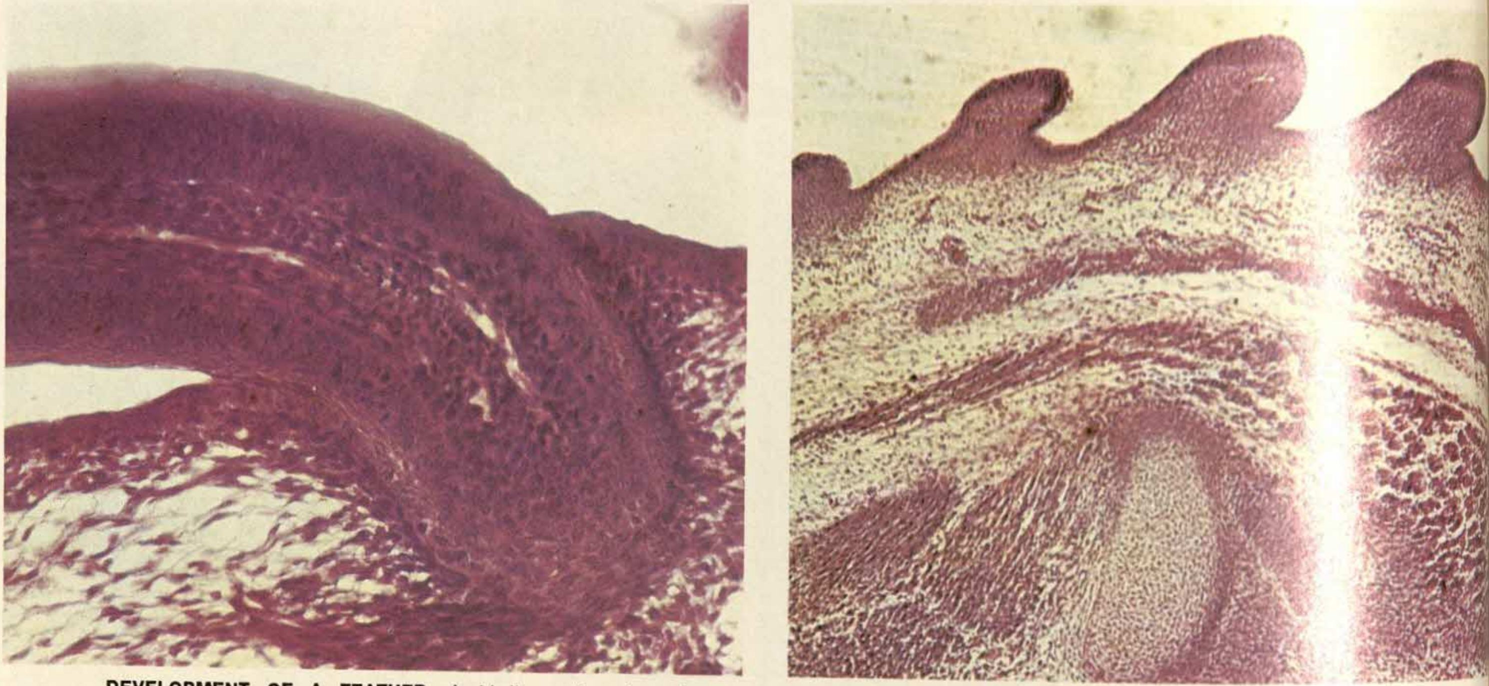
CILIATED PSEUDOSTRATIFIED COLUMNAR EPITHELIUM—In the respiratory tract the free surface of the epithelial cells (Illustration 6a) bears cilia, which by their beating motion sweep the tract clean of debris and bacteria. The cells are arranged in a single layer, but because their nuclei are at different levels they have the appearance of stratified epithelium (Illustration 6b). (1,300 X)

INTERCELLULAR CONTACTS

Epithelial cells are closely packed together, and it is difficult to separate them from each other. The spaces between them are so minute that they are visible only with the great magnification of the electron microscope. Small dark areas called desmosomes occur occasionally along the junctions of two cells. The desmosomes contain fine protoplasmic strands that were once thought to extend from cell to cell and thus served to bind the cells together; however, recent studies with the electron microscope reveal that none of these strands reach across the intercellular space. In other areas, especially in the parts of the lateral walls that are near the free surface, the plasma membranes of adjacent cells are in direct contact with each other. These areas, which appear dark even under a light microscope, are called terminal bars. The wavy outlines of the cells in some epithelia probably contribute to the strong adherence of these cells, for they interlock with one another like the pieces of a jigsaw puzzle.

THE PLUMAGE OF BIRDS | structure, form, and color

Long before bird watching became a serious pastime, man thrilled to the beauty of these winged creatures. The beauty of birds, of course, derives from their feathers, a form of body covering shared by no other animal.



1a

1b

DEVELOPMENT OF A FEATHER—A bird's feather arises from a small papilla (Illustration 1a) that slopes backward. The final feather arises from the outer epidermal portion that undergoes cornification and dies. The inner dermal layer of the papilla develops blood vessels that nourish the developing feather. (62 X) Illustration 1b is a longitudinal section of the base of a developing feather; the outer

But feathers serve a more important function than beauty. They protect the bird from the cold, and they provide the modification of overall body shape that makes it possible for birds to fly.

THE DEVELOPMENT OF A FEATHER

When down feathers begin to form on a chick, the skin is covered by minute projections—the papillae—that slant backward. Each papilla consists of dermis covered by epidermis. As the papilla elongates, the epidermal cells form nearly the entire feather. When the feather is complete, it consists of hard, dead, cornified epidermis. The dermis contains many blood vessels that nourish the feather while it is growing.

While the down feather is developing, a depression forms around the papilla. This depression is the feather follicle; it contains embryonic cells from which a new feather is produced when the old feather is lost during molting or by accident. When growth is complete, the feather consists of a central axis, the upper part of which is the rachis, or shaft. The lower part is the calamus, or quill.

Attached to the rachis are long, thin processes, the barbs, that vary in length and softness. The barbs also have similar but smaller processes called barbules, and some of these have minute hooks, or hamuli. The hamuli of one barbule interlock with one or more barbules of an adjacent barb. This gives the entire structure a certain degree of rigidity and yet permits some flexibility. The complex of barbs and barbules forms a web or vane on either side of the rachis.

The calamus contains two openings (the upper umbilicus and lower umbilicus), the lower of which serves to take in the nutritional substances required by the feather itself.

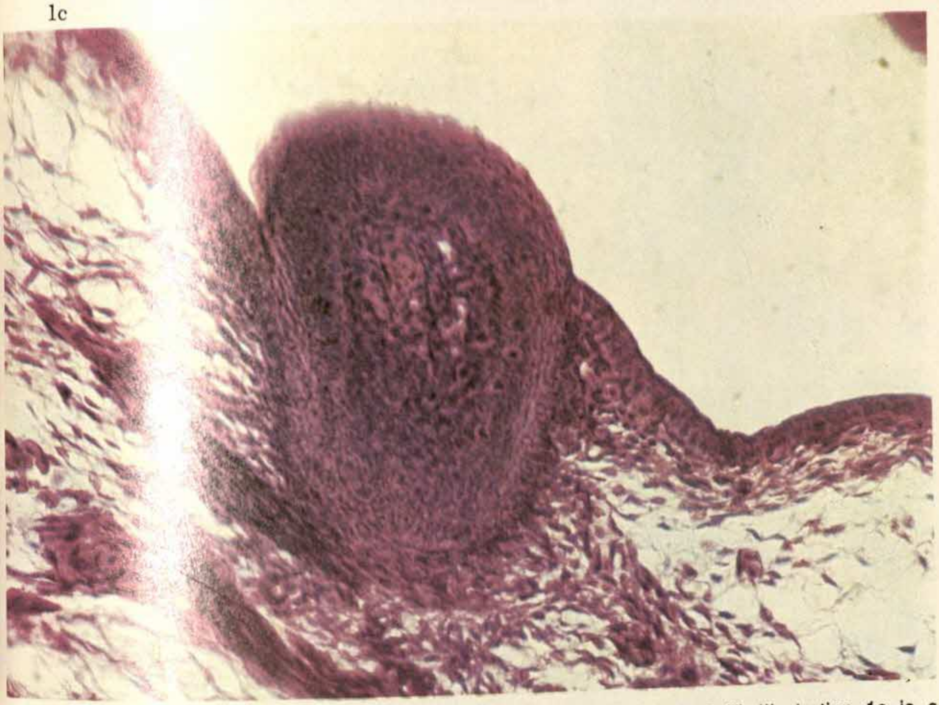
TYPES OF FEATHERS

Four main types of feathers exist: down feathers, contour feathers, semiplumes, and filoplumes.

Down feathers, or plumules, are found mostly on young birds. Down feathers have no rachis; the barbs grow from the tip of the calamus, and the barbules do not carry hamuli. Light and fluffy, these feathers provide warmth to newly hatched chicks. Later they are replaced by other feathers, chiefly contour feathers. (Down feathers do occur under the contour feathers of adult birds of some aquatic species.) Contour feathers cover most of the body of an adult bird. They have definite shafts and webs and are usually fairly rigid. Their sizes and colors vary, and their shapes may be simple or complex.

Contour feathers are divided into several categories, depending on their function and location. The wing feathers are known as the remiges. The primary remiges are those that grow on the portion of the wing that corresponds to the hand of a man; the secondary remiges grow on the portion that corresponds to the forearm. The number of primaries varies between nine and twelve, and the number of secondaries varies from nine to forty. Strong and quite large, the remiges are covered by other, smaller feathers arranged in overlapping series like roof tiles; these are known as coverts or tectrices.

1c



cornified epidermis is visible. In the center is the highly vascularized connective tissue. Surrounding the base of the feather is a sheath of epidermal cells. (325 X) Illustration 1c is a cross section of the base of the developing feather, showing the same layers. (200 X)

Tail feathers are contour feathers known as rectrices; they control the direction of flight. Rectrices grow in a semicircle on the uropygium (the base of the tail) and vary in number from twelve to fifteen. Other contour feathers cover the head and body. A characteristic common to almost all species of birds is that the contour feathers grow only in certain areas of the bird's skin, rather than being evenly distributed over the entire surface of the bird's body. These areas are known as pterylae; they alternate with other areas known as apteria, which are covered with small scales resembling those of reptiles.

Semiplumes, which occur under contour feathers, are intermediate between down feathers and contour feathers. They have a short rachis, but because they have no interlocking hamuli they are fluffy like down feathers.

Filoplumes look more like hairs than feathers. Each filoplume has a long slender rachis with only a few barbs (or none) near its tip. Most filoplumes are small and inconspicuous and grow among the contour feathers. Longer ones may have ornamental or sensory functions.

Because birds have to maintain their efficiency in the air, they go through the periodic process of molting. Subjected to wear and tear, the contour feathers age quickly and must be replaced if they are to do their job properly. As a general rule, molting takes place in autumn, although in some species it occurs two or more times a year. The contour feathers drop from the bird, and new ones grow in their place. Usually only a few feathers are shed at a time, but ducks lose all their flight feathers at once and cannot fly until they are replaced.

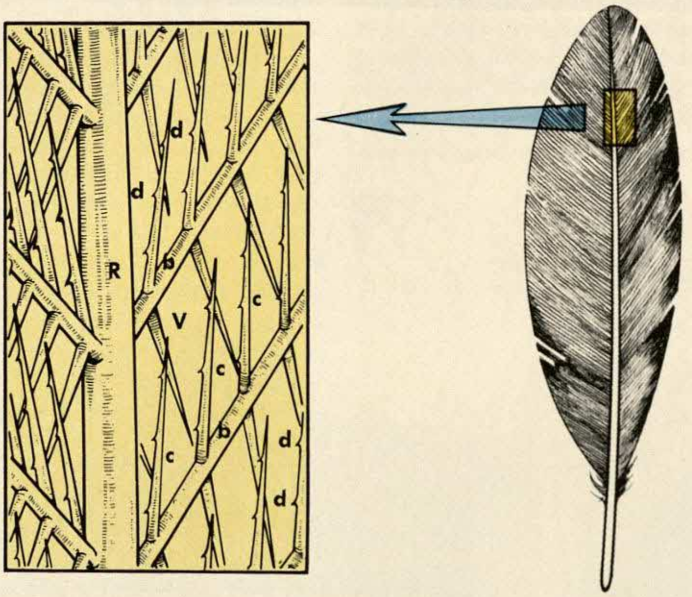
COLOR IN THE BIRD WORLD

The colors of birds are conditioned by the climate and the season. Where the winter is long and the weather cold and foggy, the plumage of birds is often dull or grayish. Black, gray, and white are the colors usually found in seabirds or birds of prey. Many tropical birds and some of the Temperate Zone have brilliant colors. Within a species, birds that live in arid regions tend to be pale; and those that inhabit regions with high rainfall tend to be dark.

The colors of feathers are produced in two different ways. Some are due to the presence of pigments, while others are due to the structure of the feathers.

2

STRUCTURE OF A FEATHER—The contour feather on the right is a wing primary. On the left, the enlarged portion of the feather shows the rachis **R,** or the axial shaft of the feather. On each side of the rachis is a vane **V** made up of a large number of barbs **b.** Each barb carries several barbules **c,** and each barbule has several hooks, or hamuli **d.**



Three main groups of pigments are present in feathers. Melanins, which are black, brown, or dull yellow, occur in the form of granules produced in special pigment-producing cells. Lipochromes are fat-soluble pigments; these are carotenoids that are red, orange, or yellow. Cardinals, orioles, and canaries owe their colors to lipochromes. Porphyrin pigments are red, green, or brown; these pigments, which chemically resemble the hemoglobin of the blood, occur in the feathers of bustards and touracos.

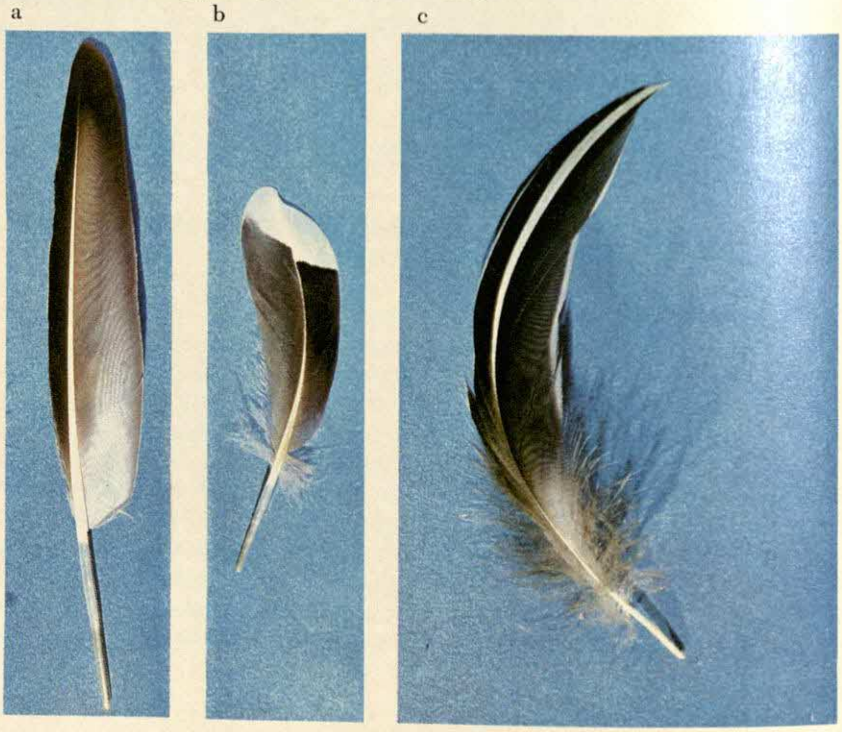
Structural colors are due primarily to reflection and refraction of light, but they may be associated with pigments. No blue pigments exist in feathers. The brilliant blue of the blue jay or indigo bunting is due to the presence of a special outer layer of blue-reflecting cells in the feathers. The underlying cells have brown melanin granules that absorb light of other wavelengths. The green feathers of some parrots have a similar arrangement, but the reflecting cells reflect green light, and the pigment of the underlying cells is yellow.

Iridescent colors, like those of hummingbirds and peacocks, are found in feathers that have broad, flat barbules that overlap each other. The barbules are covered by thin layers of a horny substance that produces interference colors similar to those produced by soap bubbles or thin films of oil on pavements. The color seen depends on the angle of incidence of the light; a small movement will cause the colors to change quickly. Iridescence does not depend on an underlying layer of pigment, but such a pigment gives a metallic sheen to the iridescence. White feathers, of course, lack pigment completely. The white color is due to the reflection of light from the surfaces of the many tiny air-filled spaces among the feathers.

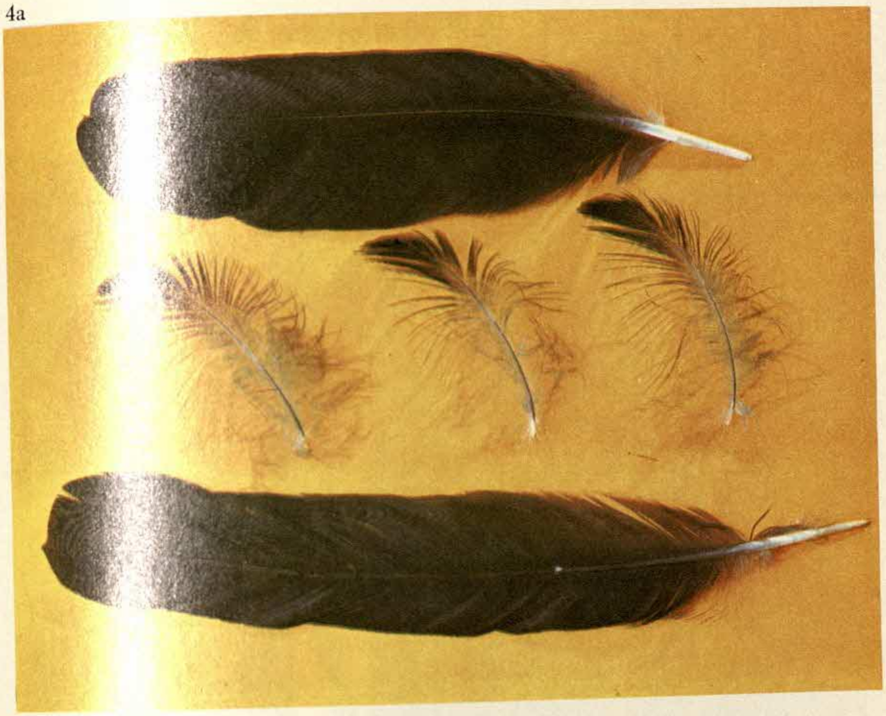
Seasonal color changes in birds may be due to molting, the new feathers having colors different from those of the old. Also, light-colored feathers wear away faster than dark ones, and thus seasonal changes may be due to the erosion of light-colored tips from otherwise dark feathers. Colors may also fade as feathers age; and when feathers are dead, they cannot produce new pigment.

3

THREE WING FEATHERS—These illustrations show three different types of wing feathers of the garganey, a European teal. Illustration 3a is a long, slender wing primary; Illustration 3b is a wing secondary; Illustration 3c is a curved scapular, less rigid than the primaries and secondaries, with a white patch running lengthwise.



4a



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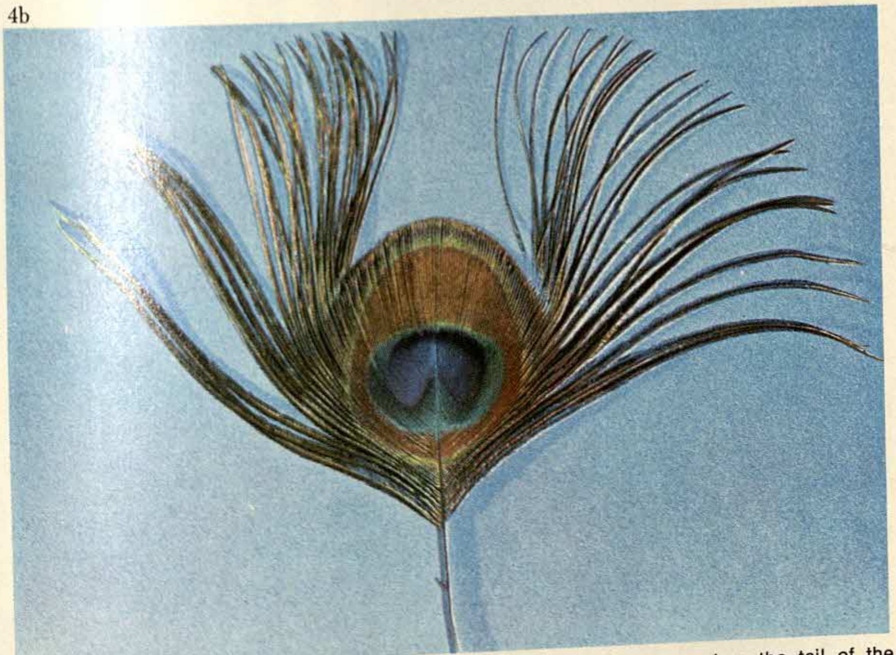

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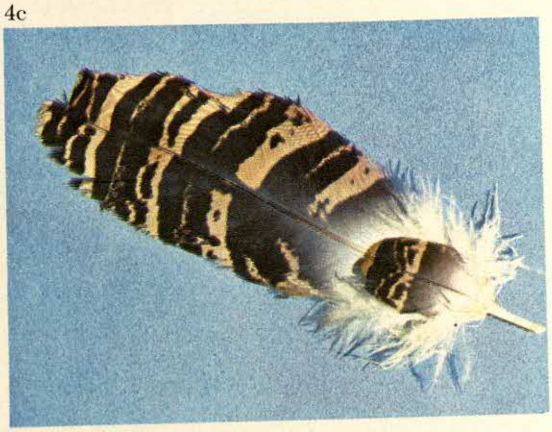
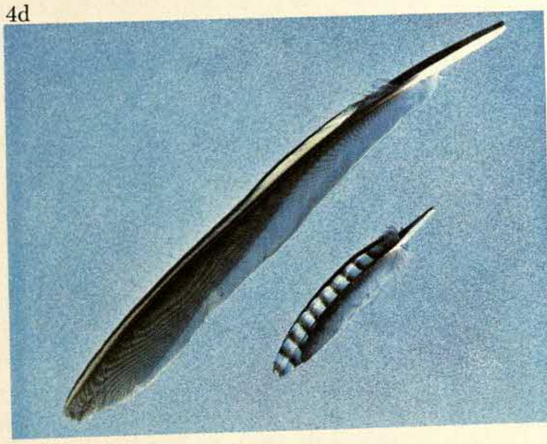
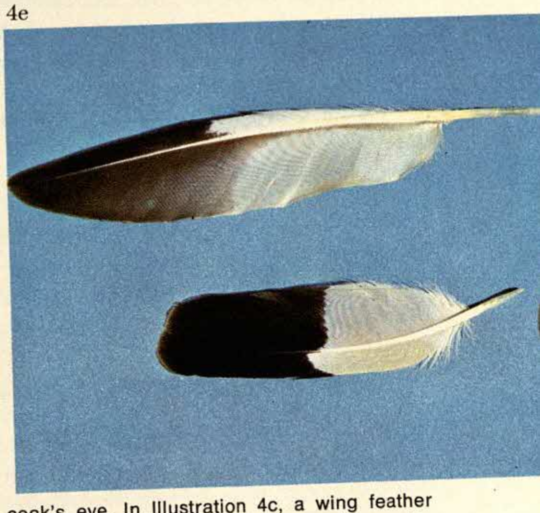


4d



4e



SOME TYPES OF FEATHERS—Illustration 4a shows two contour feathers and three down feathers of the crow. The crow's plumage is very dark on the outside, but when ruffled it takes on the color of mother-of-pearl. Illustration 4b shows one of the characteristically gorgeous feathers that adorn the tail of the peacock. On the outside the metallic-colored barbs are long and separate from each other, while in the center they are shorter and join together, forming the characteristic splash of vivid blue-green coloring known as the peacock's eye. In Illustration 4c, a wing feather and a down feather of the bustard grow together. Illustration 4d shows two contour feathers from the wing of a jay. Illustration 4e shows a long primary wing feather and a shorter tail feather of the lapwing.

CONNECTIVE TISSUE | holding the body together

If the animal body is to perform its various functions successfully, the parts that make it work must be arranged in proper physical relationship with one another. The function of holding all these parts together is assumed by the connective tissues that line the various cells and organs of the body. Because connective tissue envelops other body parts, it is in effect the pathway by which blood vessels and nerves reach these parts. Other functions of connective tissue include support of the body and the fighting of infections.

Connective tissue has three components: ground substance, intercellular fibers, and cells. The cells and fibers are embedded in the ground substance. The types, arrangements, and proportions of these components produce three different types of connective tissue in adults: connective tissue proper, cartilage, and bone.

GROUND SUBSTANCE

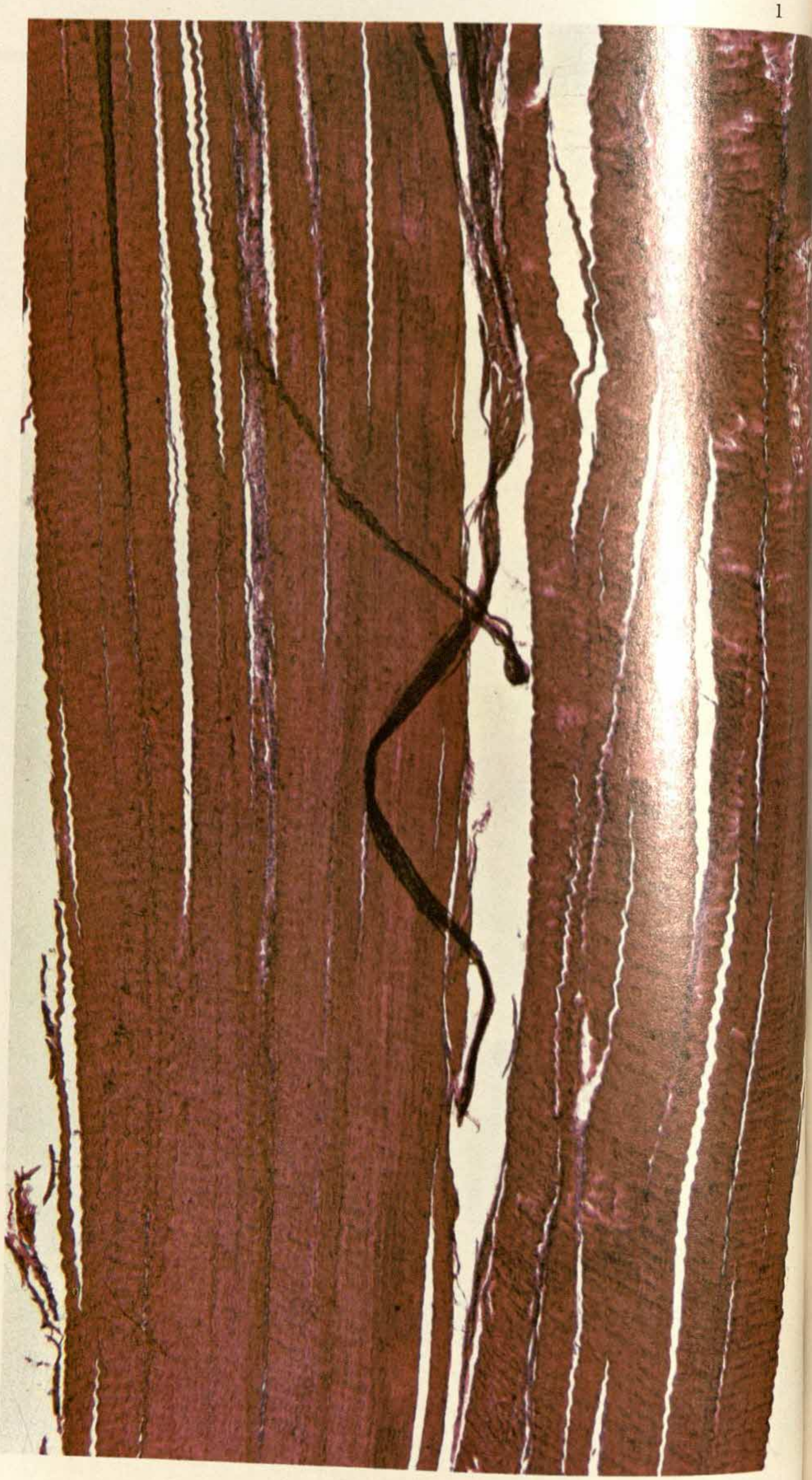
Ground substance may be nearly fluid, semisolid, or solid. Its chemical composition varies from one tissue to another, but basically it consists of complex substances known as mucopolysaccharides. Two principal types of these substances are known: hyaluronic acid and chondroitin sulfate. Hyaluronic acid prevents the spread of many kinds of infections through the body, but some bacteria possess the enzyme hyaluronidase which digests hyaluronic acid and permits more rapid invasion of tissues.

INTERCELLULAR FIBERS

Embedded in the ground substance are proteinaceous fibers. These are of three types: collagenous (or white) fibers, elastic fibers, and reticular fibers.

Collagenous fibers consist of long polypeptide molecules. Three of these polypeptide molecules (two are the same, and one is slightly different) are coiled around each other forming a larger mole-

1



COLLAGENOUS FIBERS OF A TENDON— This is a longitudinal section of a tendon under the microscope. The fibers, with their characteristic wavy edges, appear as ribbons in a parallel arrangement. (55 X) cule, tropocollagen. Many tropocollagen molecules are united into a much larger strand, the collagen fibril. The diameter of this fibril varies from 200 to 1,000 Å (about 0.0000008 to 0.000004 in.). Under the electron microscope it has a regular pattern of transverse striations that repeat every 640 Å (about 0.0000026 in.). Several collagen fibrils form a single collagenous fiber that is visible under a light microscope.

Collagenous fibers are tough and cannot be stretched appreciably, but they are pliable. They are the main fibers in tendons and ligaments.

Elastic fibers, as their name suggests, are stretchable. Reticular fibers are extremely fine and are difficult to see except in specially stained preparations. Both of these fibers are composed of proteins similar to collagen.

CELLS OF CONNECTIVE TISSUE

The cells of connective tissue include several types: fibroblasts, macrophages (histiocytes), plasma cells, mast cells, and wandering blood cells.

Fibroblasts are large, flat, branched cells with several long protoplasmic processes. The tips of these processes may touch those of other fibroblasts. Fibroblasts control the production of the intercellular fibers that are formed in intercellular spaces rather than within the fibroblasts themselves. The cells secrete substances that initiate fiber formation in the ground substance, and they may also contribute to the formation of ground substance. Most fibroblasts remain fixed in position, but they can move slowly toward wounded tissue. Here they divide and form more extracellular fibers.

Macrophages look much like fibroblasts, but they are capable of amoeboid movement and have the important characteristic of phagocytosis: they ingest bacteria and other foreign bodies as well as dead blood cells. Macrophages comprise the major part of what is known as the reticuloendothelial system. These scavenger cells usually are fixed in position, but they, too, can move to a site of infection.

Plasma cells are not so common in connective tissue as they are in lymphoid tissue and in the mucous membranes of the digestive tract. The ovoid cells have somewhat irregular outlines, and the chromatin in the nucleus is arranged in a peculiar cartwheel pattern. These cells produce antibodies that provide immunity to many diseases.

Mast cells are abundant in connective tissue and are found especially near small blood vessels. The cells are ovoid and have numerous large cytoplasmic granules. Mast cells secrete heparin, an anticoagulant, and histamine, a substance that causes irritation to tissues in allergic reactions.

The wandering blood cells found in connective tissue include lymphocytes and leucocytes, both of which seem to have defensive functions in the event of infection. Lymphocytes produce new plasma cells in some cases of bacterial invasion of the body. The role of leucocytes is not known with certainty.

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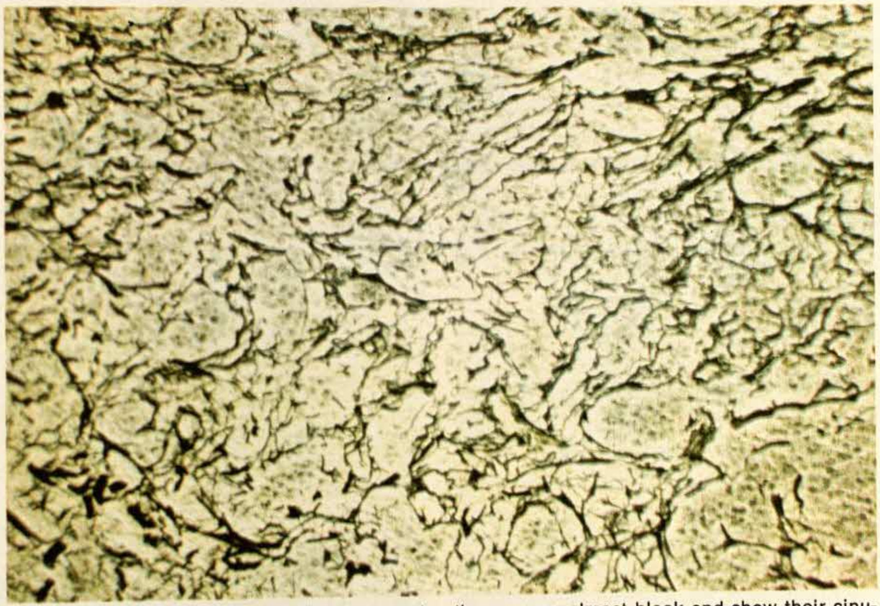


RETICULAR FIBERS—Reticular fibers are not easy to see, but impregnated with silver salts they appear almost black and show their sinuous structure.

CONNECTIVE TISSUE PROPER

Connective tissue proper is variously divided into several groups: loose fibrous connective tissue, dense fibrous connective tissue, reticular tissue, and adipose tissue.

The fibers of loose fibrous connective tissue, as the name suggests, are loosely woven together, and they are embedded in rather fluid ground substance. All of the types of fibers and cells listed above are found in loose connective tissue, but collagenous fibers, fibroblasts, and macrophages are most common. Most organs of the body are surrounded by or lined by loose connective tissue. This tissue has a spongy structure and stores water, glucose, and salt.

Dense fibrous connective tissue has a high concentration of fibers but relatively little ground substance and few cells. It is divided into two types: irregular and regular. The fibers of dense irregular connective tissue are interwoven with each other. The fibers are mostly collagenous, as in the dermis of the skin, but elastic fibers predominate around large arteries. The fibers of dense regular connective tissue are closely packed into parallel bundles. Tendons and ligaments are examples of this type of tissue. The fibers of tendons are mostly of the collagenous type, but ligaments may have either collagenous or elastic fibers.

Reticular connective tissue consists of a loose network of fine reticular fibers. Several types of reticular cells, including some macrophages, are present. This tissue is found in lymph nodes, in the spleen, and in bone marrow.

Adipose or fatty tissue consists of large spherical cells, each of which contains a large fat droplet that occupies the center of the cell. The cytoplasm and nucleus are confined to the periphery of the cell. Some fat cells are found in most connective tissues, but adipose tissues are usually found in subcutaneous tissue and near the kidneys. This tissue acts both as a storage depot for excess food and as padding for some body organs, protecting them from mechanical jarring.

EMBRYONIC CONNECTIVE TISSUE

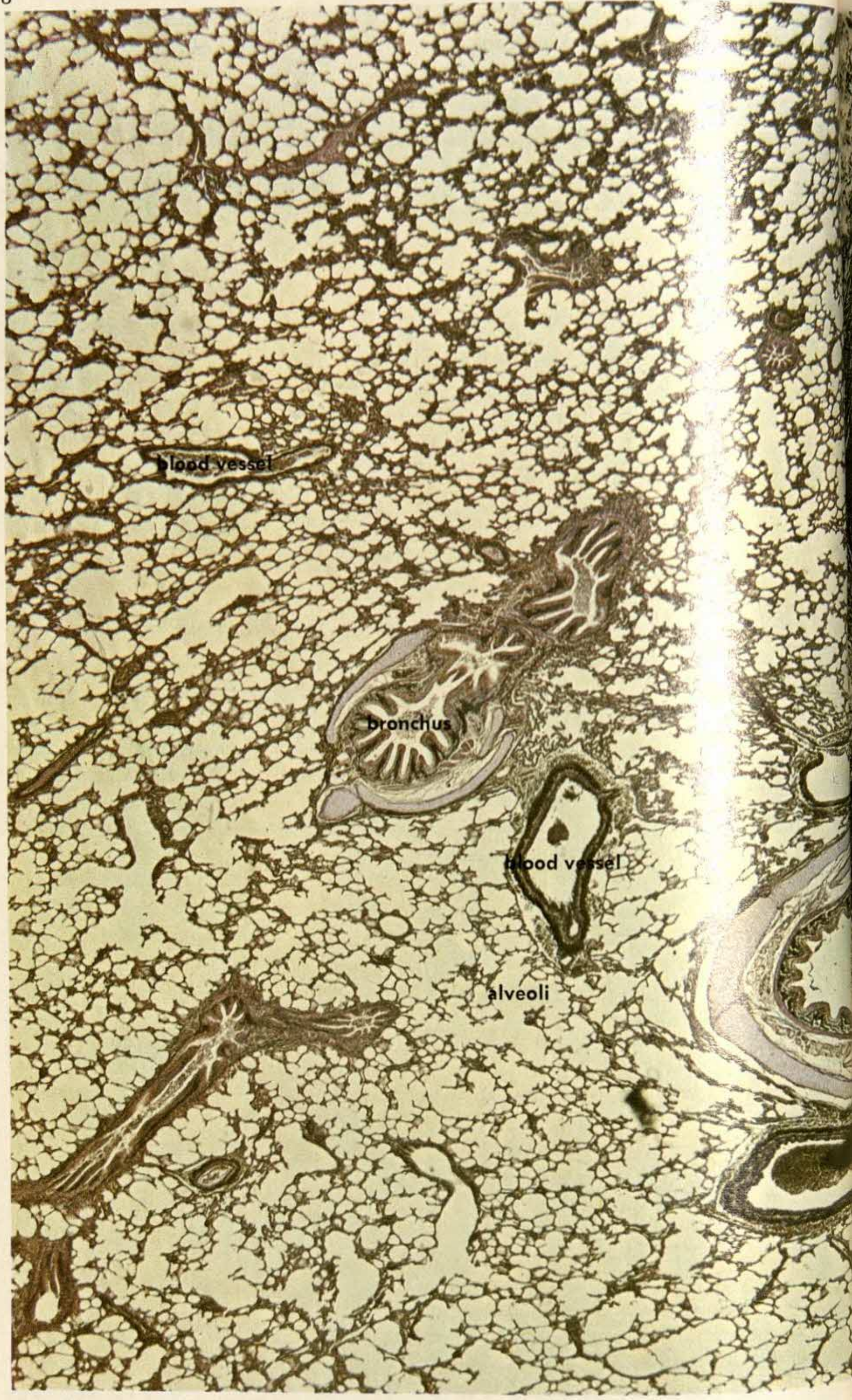
Adult connective tissues arise from an embryonic tissue called mesenchyme. The cells are loosely arranged in tissue fluid. Some, like fibroblasts, have long irregular processes. Others are amoeboid and resemble macrophages.

At a later stage mucous connective tissue develops from mesenchyme as an intercellular substance of mucoproteins is formed and collagenous fibers appear in this substance. Wharton's jelly is the name applied to the mucous connective tissue of the umbilical cord. Mucous connective tissue does not occur in the adult.

CARTILAGE

Cartilage, like other connective tissues, consists of ground substance, fibers, and cells, but it differs from other connective tissue in that it contains neither blood vessels nor nerves. Cartilage consists mostly of ground substance. Its cells,

3

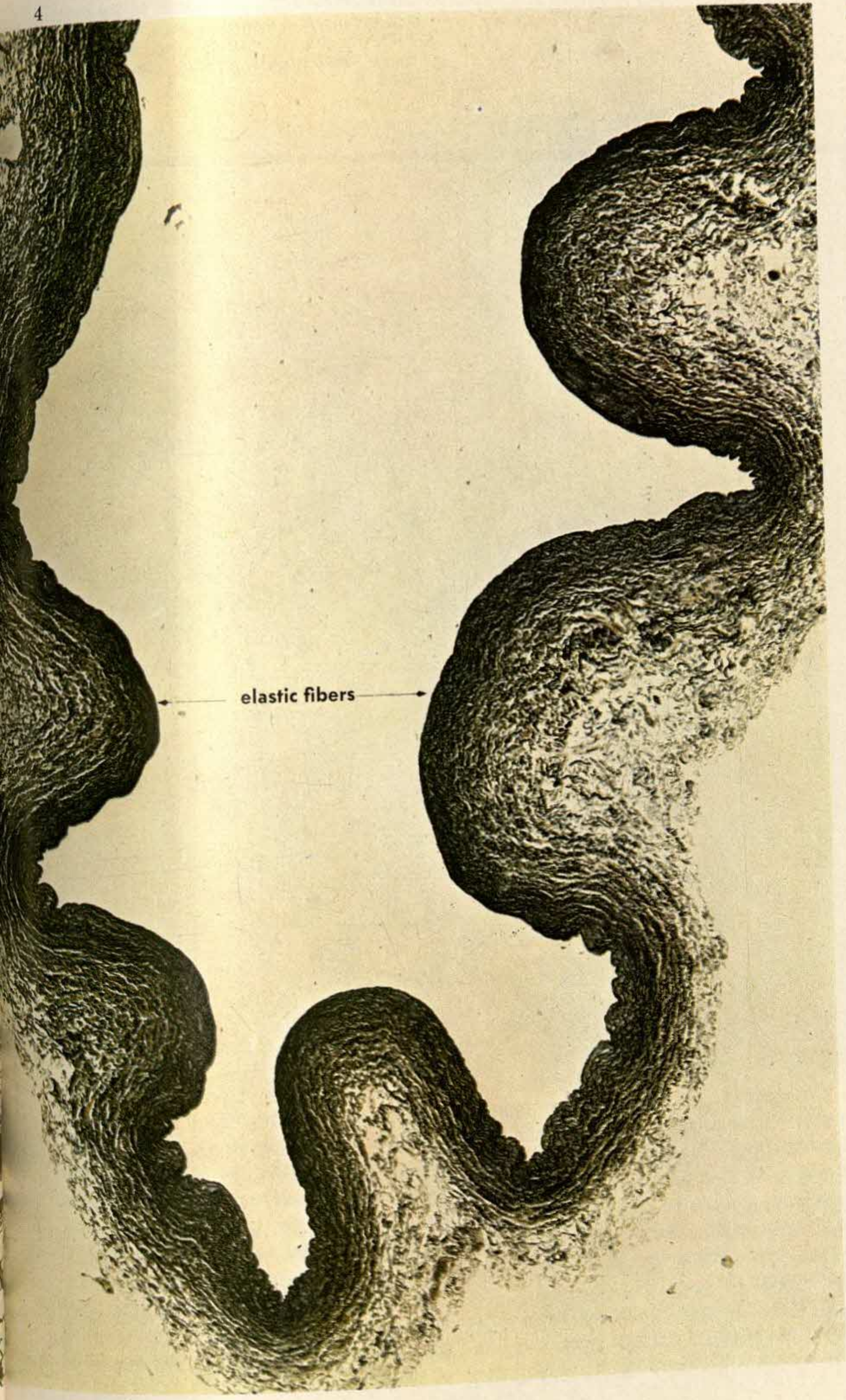


FRAMEWORK OF THE LUNG—Reticular connective tissue constitutes the supporting framework of the lung. Visible in Illustration 3 are two blood vessels, a large bronchus surrounded by elastic fibers, and some spaces, which are the pulmonary alveoli.

ELASTIC FIBERS—The elastic fibers of the walls of an artery are stained to make them easier to see (Illustration 4). They have a typical sinuous arrangement that is essential to the proper functioning of the blood vessel. (54 X).

WHARTON'S JELLY—This form of loose connective tissue (Illustration 5) is found in the umbilical cord but not in adults. Its gelatinous intercellular substance accounts for its name.

4



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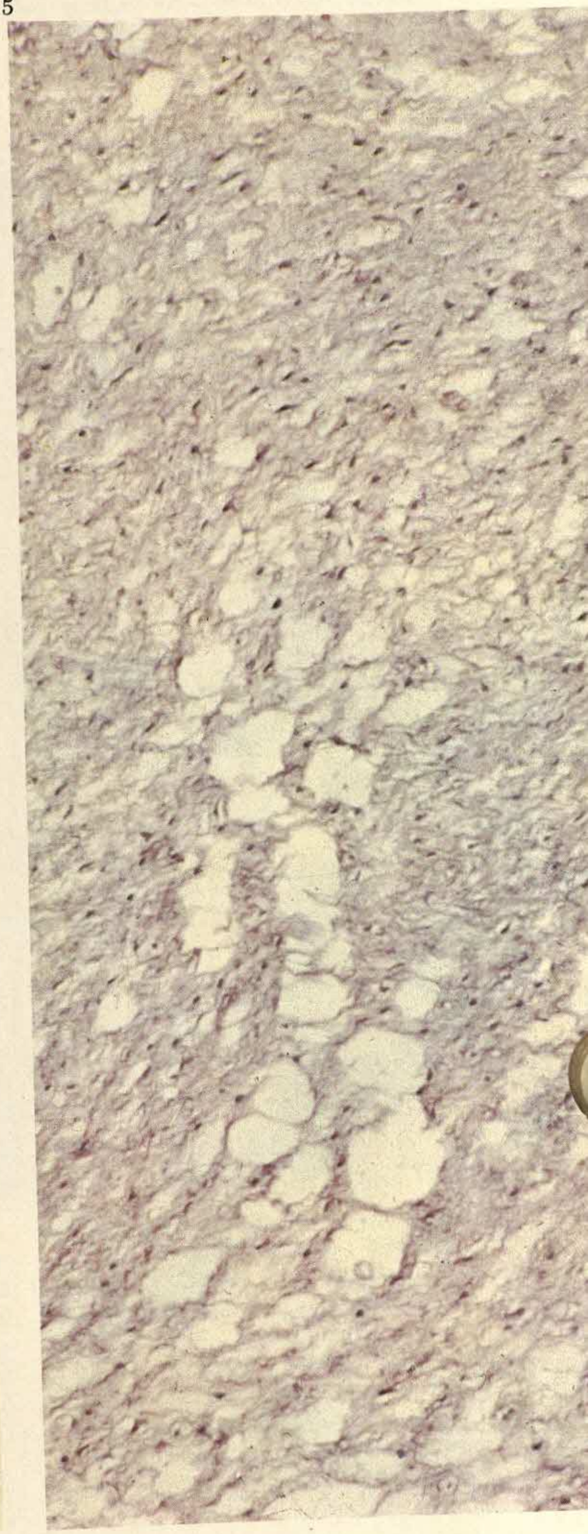

HYALINE CARTILAGE—The cartilage cells (chondrocytes) are enclosed in openings in a clear, translucent ground substance. In life, the ground substance is bluish-white. Here it is stained pink. (1,300 X)

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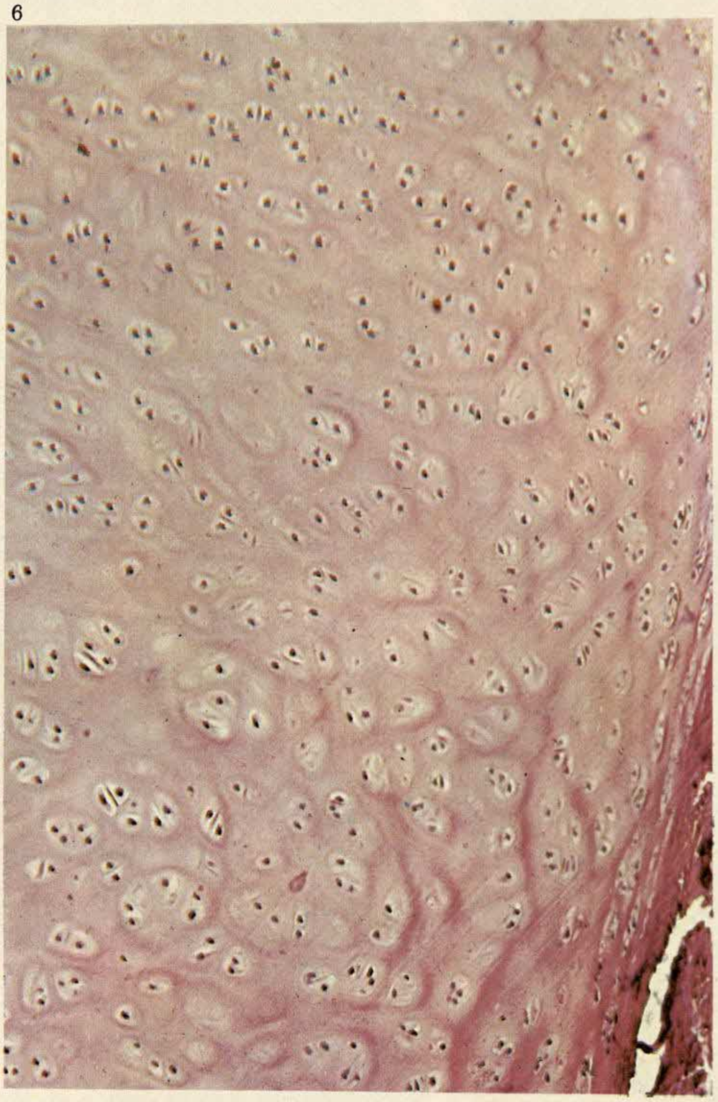
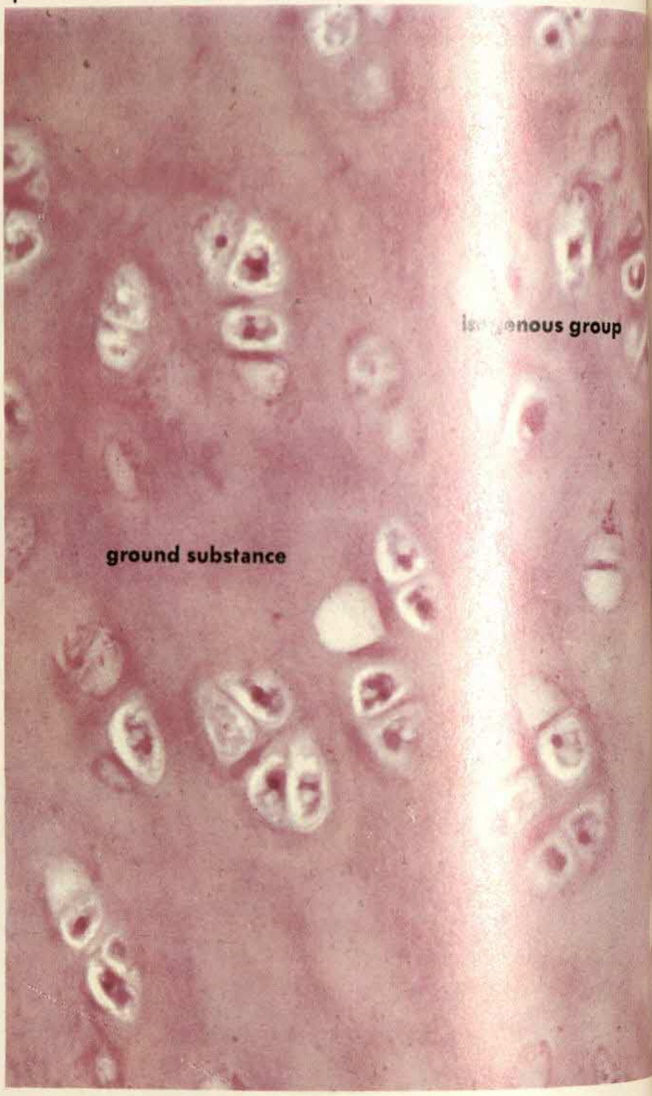


CHONDROCYTES—This detail of the preceding photograph shows groups of isogenous cells. All the cells of a group arose from a single chondrocyte. Nuclei can be clearly seen.

7



called chondrocytes, are confined to cavities in the ground substance.

There are three types of cartilage: hyaline cartilage, elastic cartilage, and fibrous cartilage.

Hyaline cartilage derives its name from the fact that under the light microscope the ground substance appears to be clear and homogeneous. As seen under the polarizing microscope, small collagen fibers are randomly arranged.

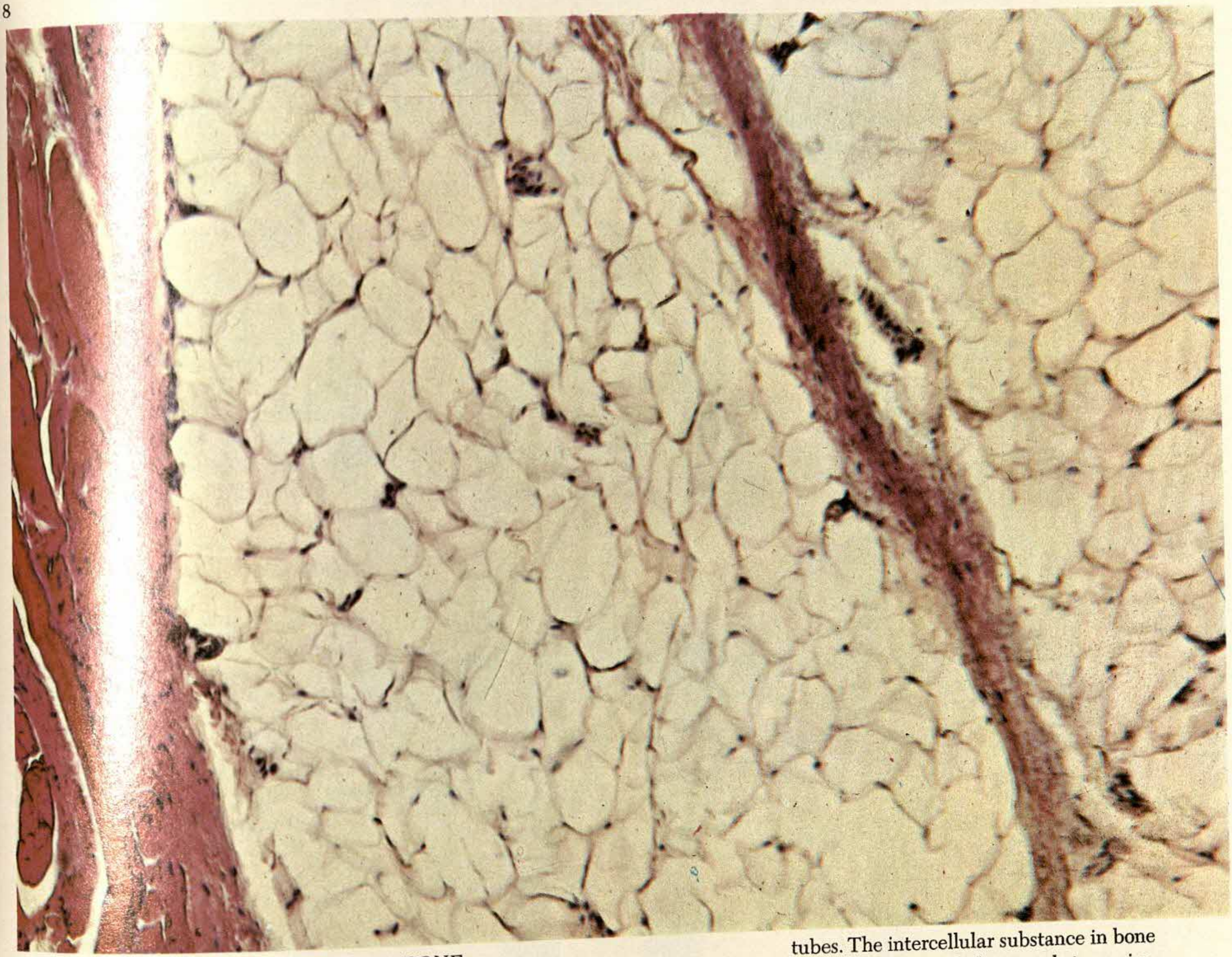
Chondrocytes of this tissue are spherical and have a centrally placed nucleus. In young individuals the cells are isolated in their cavities. Later, as each cell reproduces, it gives rise to a group of five to twenty cells. These cells are called isogenous, which means, literally, of the same origin.

Hyaline cartilage is a tissue that resists pressure and has a marked elasticity. For this reason it is often found covering the surfaces of the joints, which are subjected to great mechanical stress. In the developing human fetus, the skeleton is first laid down as cartilage, most of which is later replaced by bone. In sharks and rays the skeleton is completely cartilaginous during the entire life of the fish.

Much less common in man than hyaline cartilage is elastic cartilage, which is found in the epiglottis, in the ear, and in some nodules of the larynx. It differs

ADIPOSE TISSUE (FAT)—The center of each cell is occupied by a large fat droplet. The thin peripheral layer of cytoplasm contains the nucleus. A cell sectioned at the level of the nucleus has a "signet ring" appearance. (200 X)

8



from hyaline cartilage in that it has elastic fibers as well as cartilaginous fibers and also because the isogenous groups are much smaller and are composed of only one, two, or three chondrocytes.

Fibrous cartilage is very rich in collagen fibers, which give it solidity and the ability to resist compression. Fibrous cartilage is the basic component of the intervertebral disks, and it occurs in other joints, such as the pubic symphysis.

BONE

The cortex, or periphery, of bone is commonly compact osseous tissue, and the medulla, or marrow, contains spongy bone. This consists of tubes, plates, and bars that form a network conforming to the directions and lines of maximum pressures and tensions. Compact bone has a rich vascular network arranged in the framework of the bone in a system of tubes. The intercellular substance in bone is collagen imbedded in a substance impregnated with a mineral complex. Calcium in tissue fluid unites with free phosphate liberated locally in high concentration to form insoluble calcium phosphate crystals. There are two similar types of bone formation—intramembranous, as in the bones of the skull, and endochondral, as in the major part of the skeleton. *See also* Page 71, Volume I.

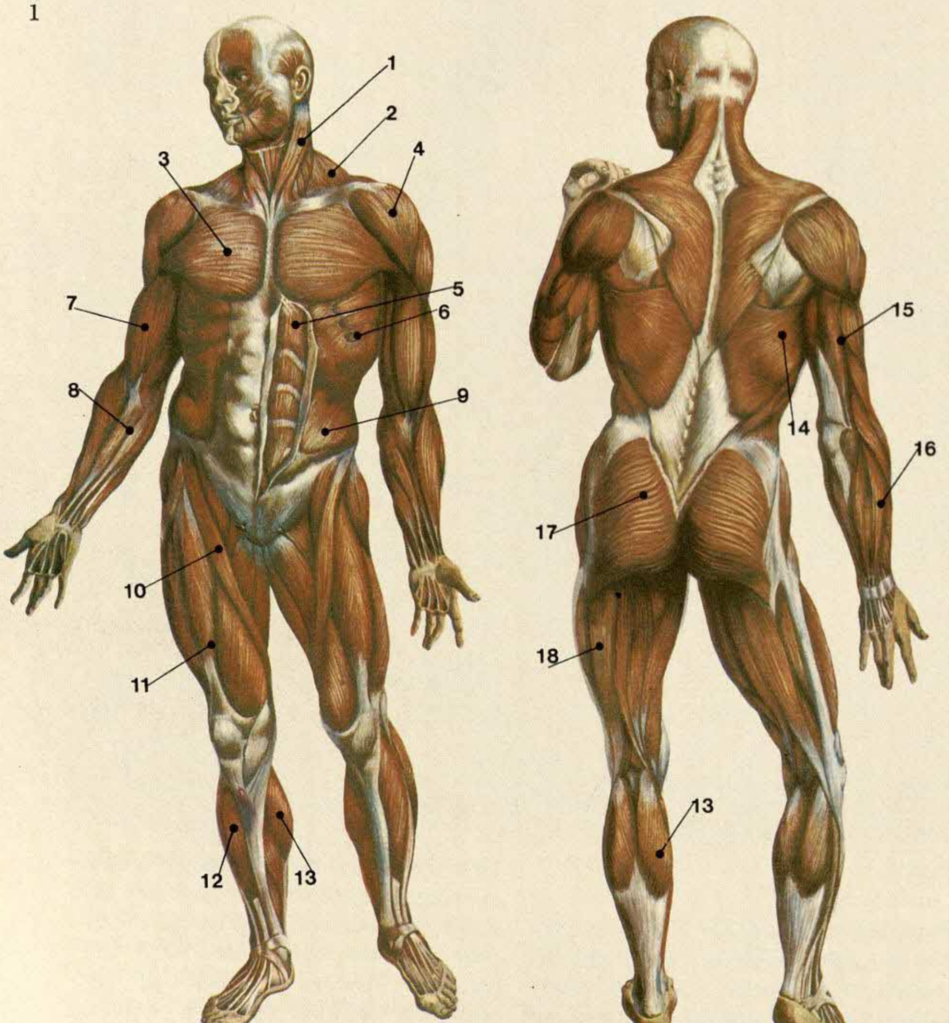
THE MUSCLES OF THE TRUNK AND LIMBS

distribution and structure

Movement is an obvious characteristic of animals. In most animals, including human beings, movement is effected by muscles, which have the property of contractility. As they contract, they change the position of some part of the body. The harmonious contraction and relaxation of the many muscles of the body is responsible for coordinated locomotion.

Most skeletal muscles have two more or less distinct ends that are attached by tendons to two different bones. As a muscle contracts, its shortening pulls one of the bones into a new position; in doing this it expends energy. When a muscle relaxes and expands, it expends no energy and thus is not able to push the bone back to its original position. This latter task is accomplished by another muscle. Most muscles occur in pairs, the two members of a pair performing opposite functions.

1



THE MUSCULAR SYSTEM—This illustration shows general views of the principal muscles of the human body:

(1) sternocleidomastoid
(2) trapezius
(3) major pectoral
(4) deltoid
(5) abdominal rectus
(6) serratus anterior
(7) biceps
(8) radial flexor
(9) obliquus externus abdominis
(10) sartorius
(11) rectus femoris
(12) tibialis anterior
(13) gastrocnemius
(14) latissimus dorsi
(15) triceps
(16) extensor digitorum communis
(17) gluteus maximus
(18) biceps femoris

TYPES OF MUSCLES

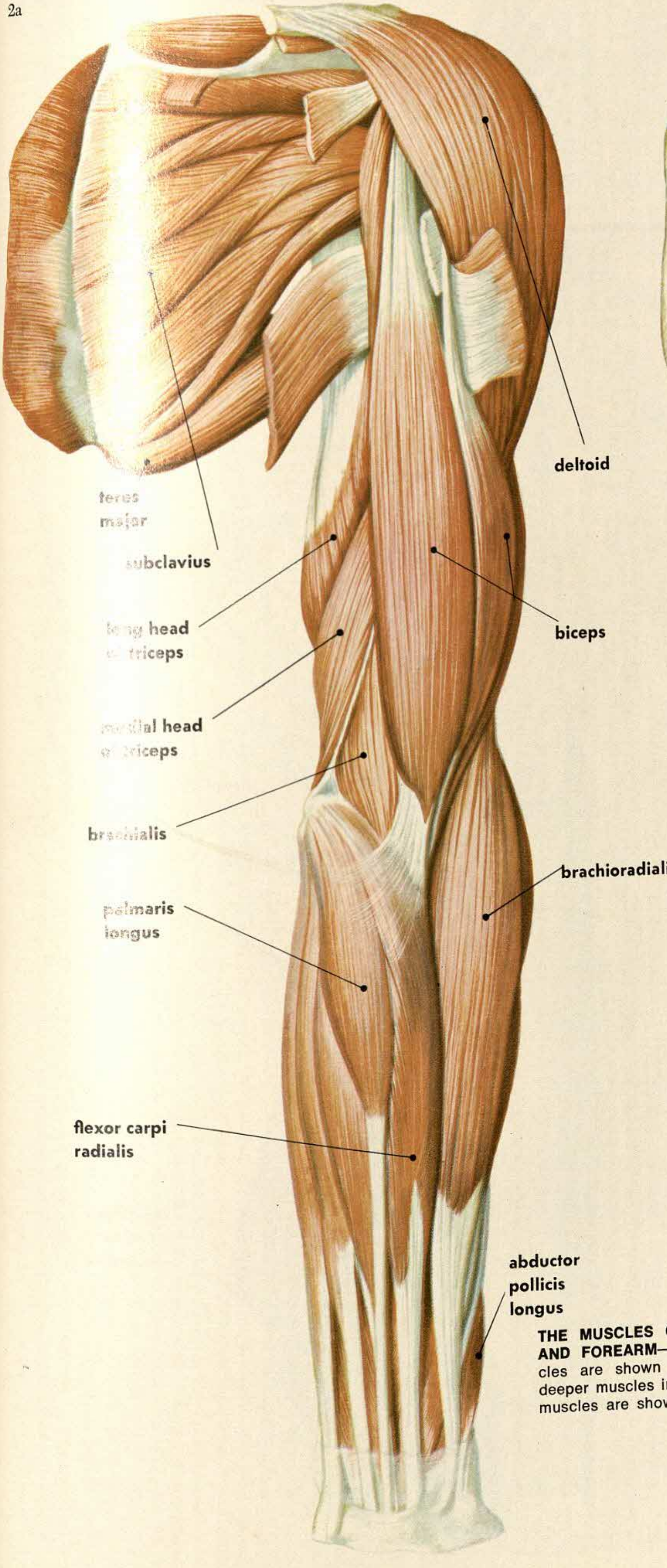
Muscles may be classified according to their functions. An abductor moves some part away from the midline of the body, while an adductor moves the structure toward the midline. The deltoid muscle (Illustrations 1 and 2a) is a triangular muscle that covers much of the shoulder joint; when it contracts, it abducts the arm by moving it away from the body. The major pectoral muscle (Illustrations 1 and 3) is an adductor that, when contracting, draws the arm back toward the body.

A flexor is a muscle that bends a joint, and an extensor straightens it. A well-known flexor is the biceps muscle (Illustrations 1 and 2a), which flexes the forearm; that is, it bends the elbow joint and brings the forearm up against the upper arm. When this muscle contracts, it produces a bulge in the upper arm that athletic boys and young men seem to enjoy exhibiting. The triceps muscle (Illustrations 1 and 2a) extends the forearm by straightening the elbow joint.

Other kinds of muscles are levators, which raise structures, and depressors, which lower them. Sphincters and dilators are muscles that surround openings such as the pupil of the eye, the opening of the stomach into the small intestine, and the anus; sphincters decrease the size of an opening or close it, and dilators increase the size or open it. A rotator rotates a body part around its axis; pronators rotate parts backward or downward; and supinators rotate parts forward or upward.

Some muscles have more than one function. The coracobrachialis (Illustration 2b) both flexes and adducts the arm, and the tibialis anterior (Illustration 6) both flexes and supinates the foot.

2a



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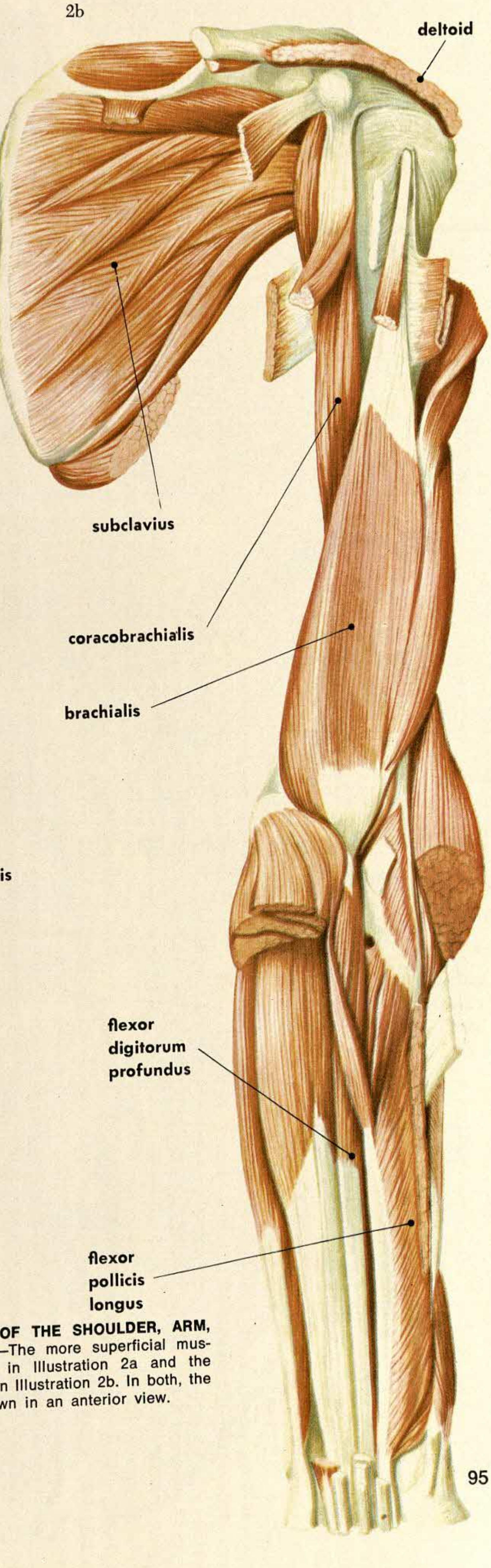
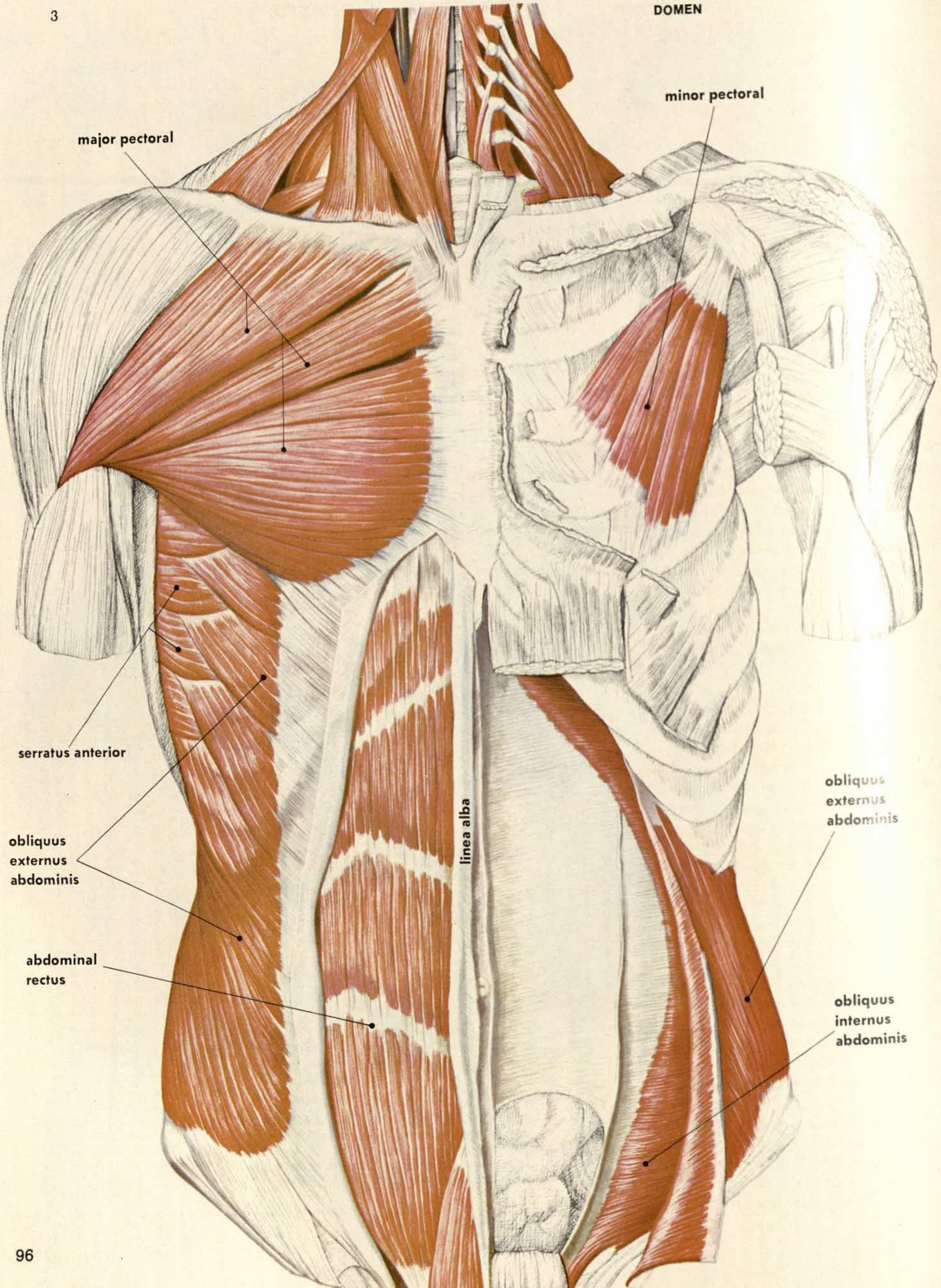


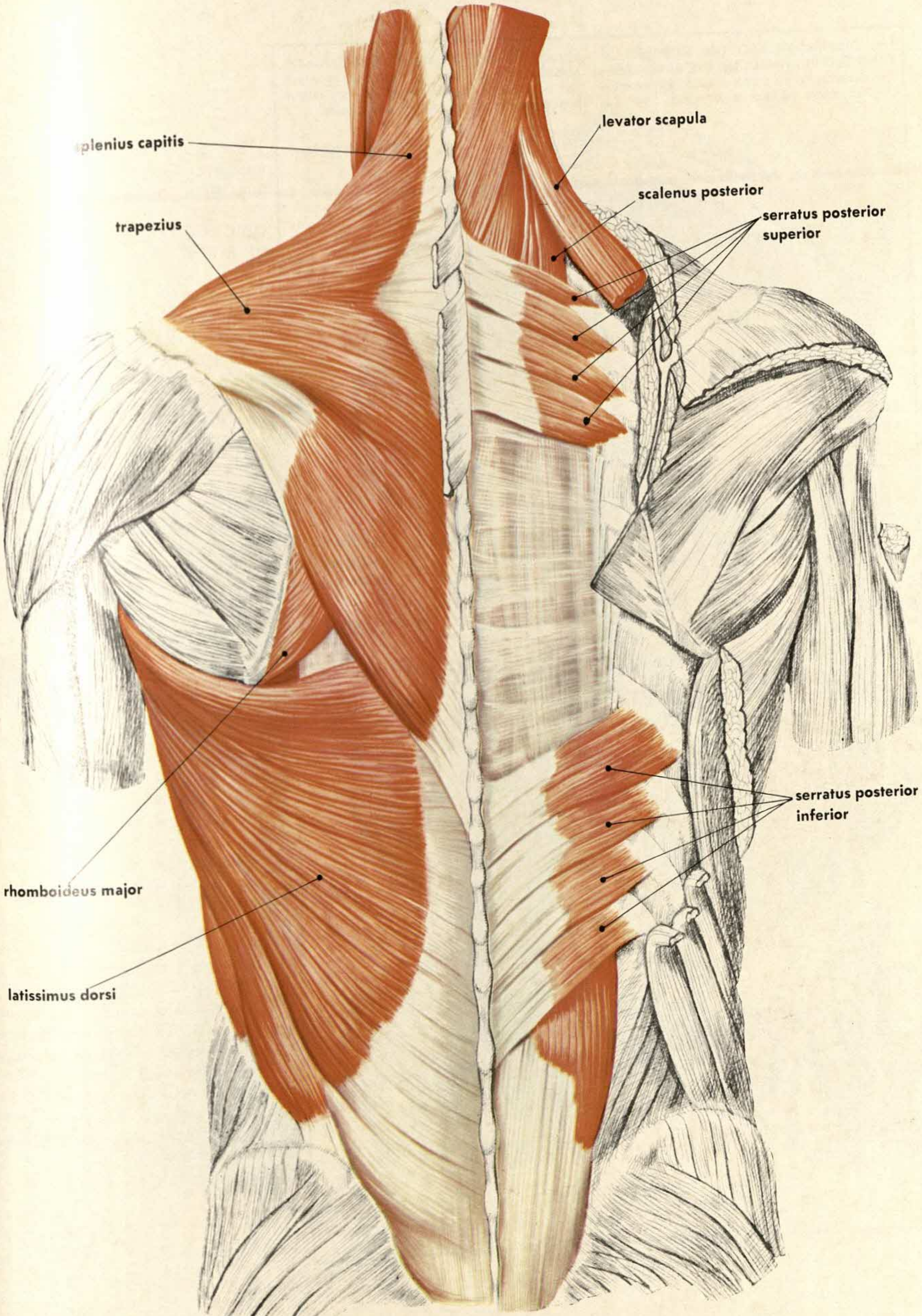
THE MUSCLES OF THE SHOULDER, ARM, AND FOREARM—The more superficial muscles are shown in Illustration 2a and the deeper muscles in Illustration 2b. In both, the muscles are shown in an anterior view.

3

THE MUSCLES OF THE THORAX AND ABDOMEN

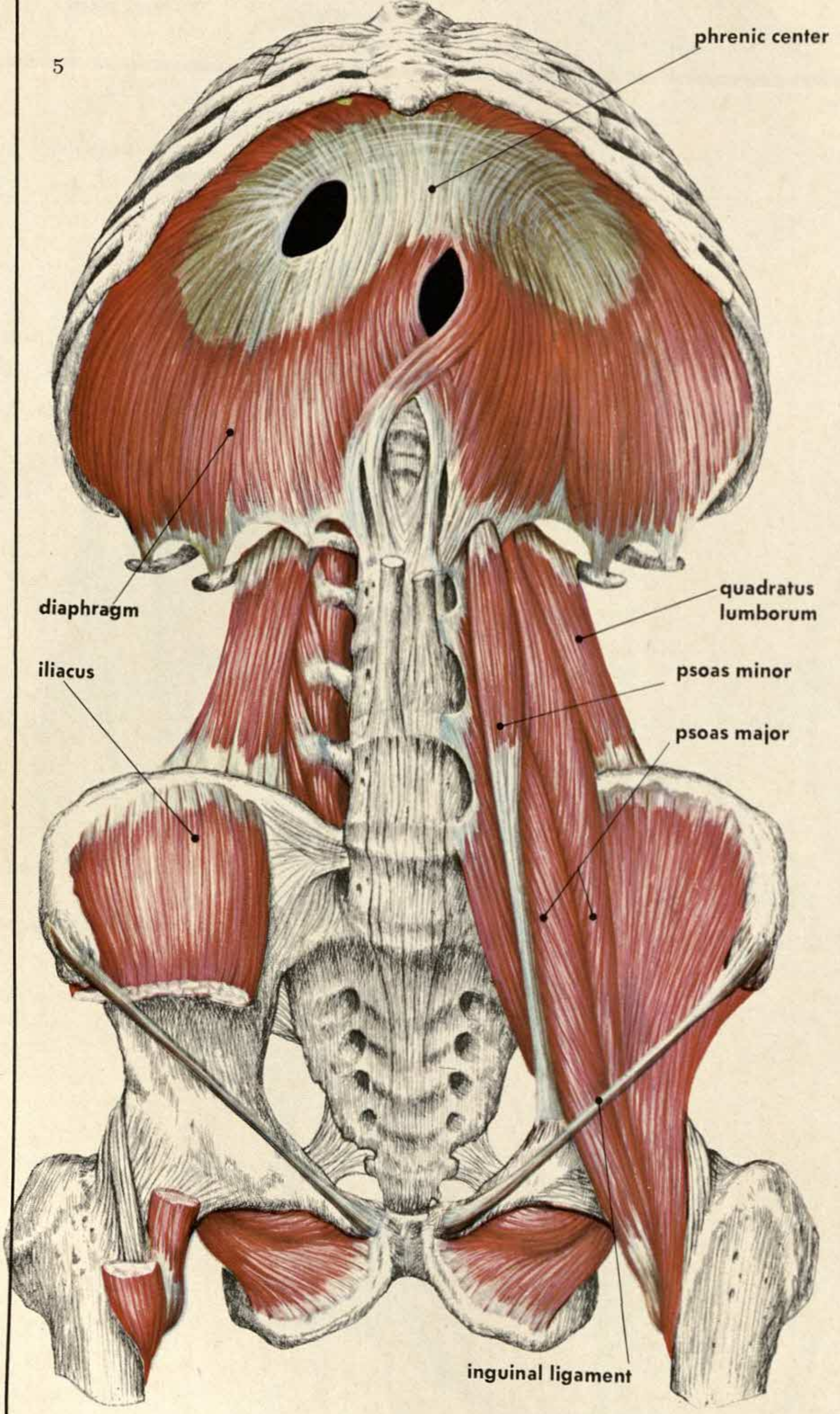

major pectoral
minor pectoral
serratus anterior
obliquus externus abdominis
linea alba
obliquus externus abdominis
abdominal rectus
obliquus internus abdominis

THE MUSCLES OF THE BACK



THE DIAPHRAGM AND THE MUSCLES OF THE POSTERIOR WALL OF THE ABDOMEN— The diaphragm is a dome-shaped laminar muscle; its lower surface is concave. The diaphragm separates the thoracic cavity from the abdominal cavity. The central zone, in which the bundles of muscle fibers are continuous with the tendons, is the phrenic center.

5



For proper coordination, when one muscle contracts, its opposing muscle must relax.

ORIGIN AND INSERTION OF MUSCLES

The points of attachment of muscles to the skeleton are their origins and insertions. Each muscle has at least one origin and one insertion. The origin is the end that remains in a fixed position when the muscle contracts; in the case of arm and leg muscles, the origin usually is the end nearer the trunk. The insertion is the end that moves when the muscle contracts; the insertions of arm and leg muscles are usually the ends farther from the trunk. The brachioradialis (Illustration 2a) arises from the lower part of the humerus in the upper arm and is inserted on the lower part of the radius in the forearm.

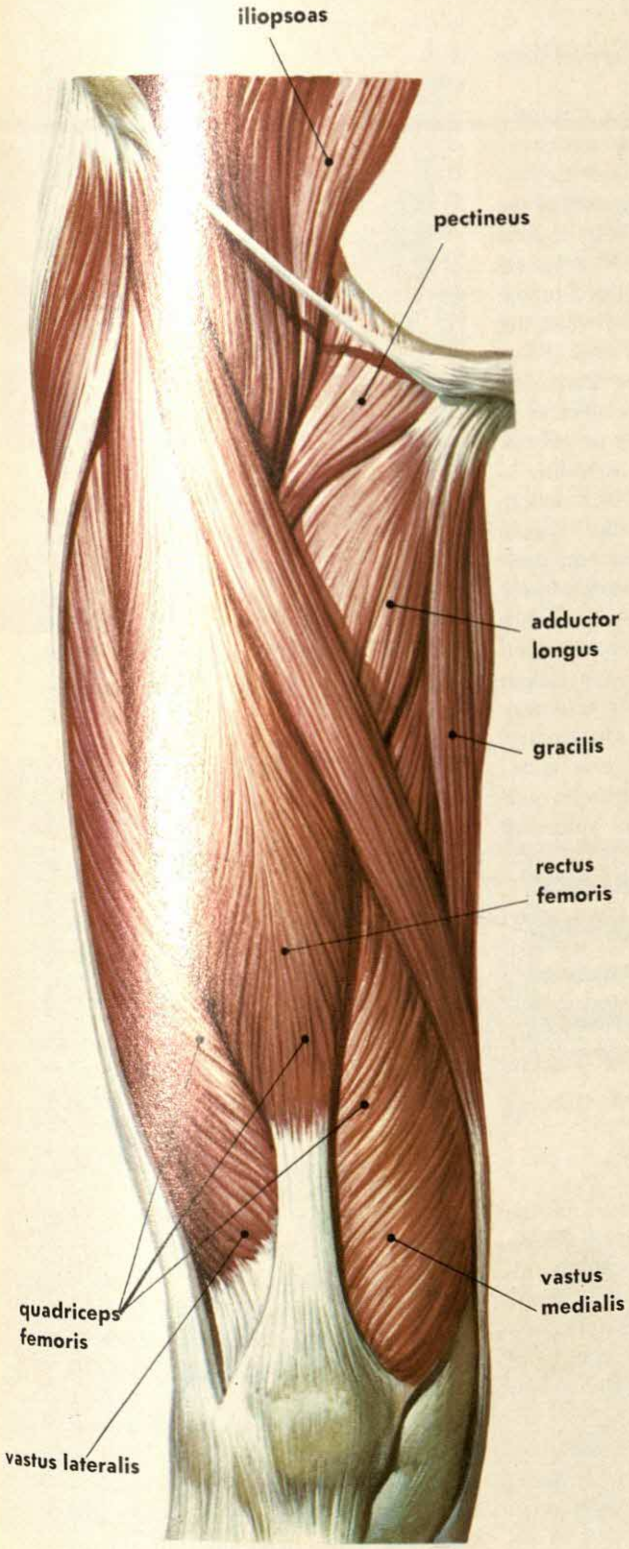
Some muscles have more than one origin or insertion. The biceps is named for its two heads which are shown in Illustration 2a; each has a different origin. The same illustration shows two of the three heads of the triceps; each of the three has a different origin. The minor pectoral muscle (Illustration [illegible]) has three distinct origins on the third, fourth, and fifth ribs. The psoas minor (Illustration 5) has two origins. The abdominal rectus muscle has three insertions on the fifth, sixth, and seventh ribs.

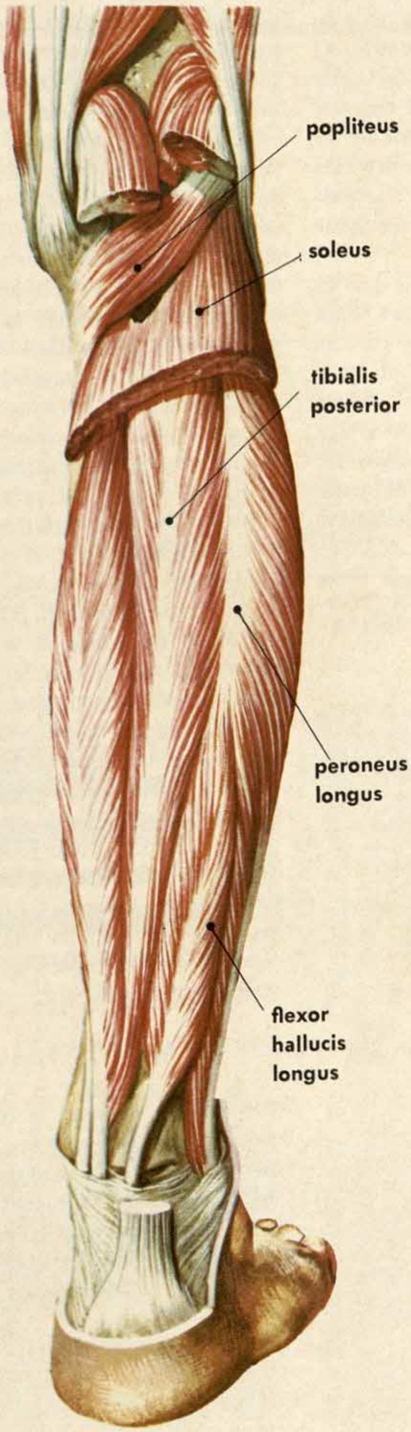
THE DIAPHRAGM

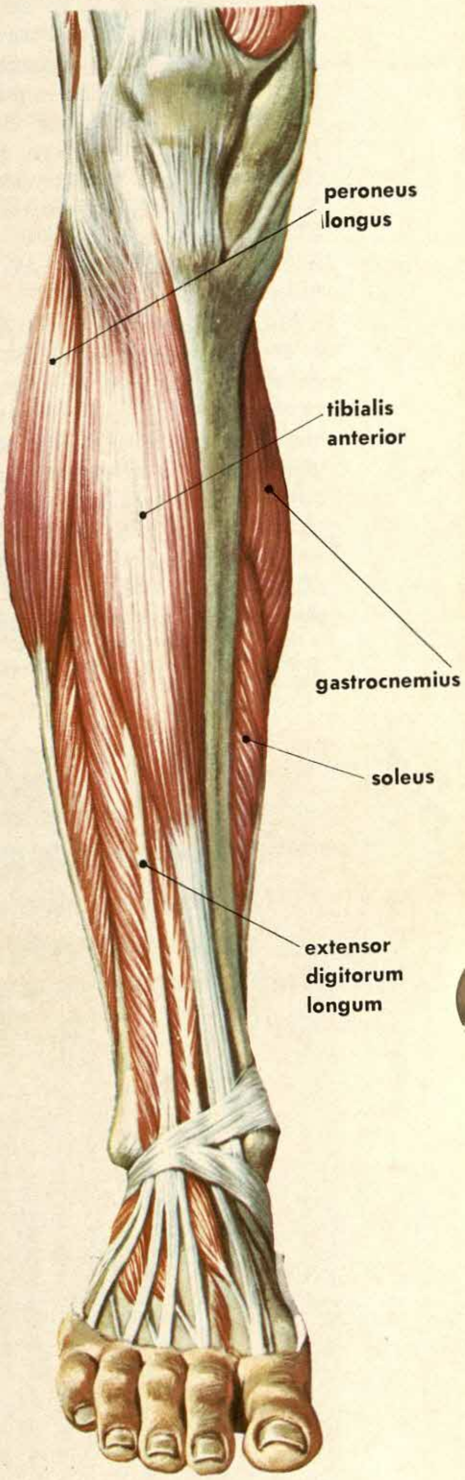
A muscle somewhat different from other muscles of the body is the diaphragm (Illustration 5), which separates the thoracic cavity (chest cavity) from the abdominal cavity. The diaphragm has three openings through which the esophagus and two major blood vessels pass. These fit tightly and make the separation of the two cavities complete. The dome-shaped diaphragm is partially responsible for breathing movements.

6

THE MUSCLES OF THE LEG







MUSCLE TISSUE | automatic and voluntary springs

The form and structure of tissues are related to the functions that they perform. Muscle tissue—whose function is contraction—is no exception to this rule. As muscle cells shorten, they cause body parts to move. The property of contractility is possessed to some extent by almost all cells, but only in muscle tissue is it so pronounced. Moreover, the contractions are coordinated, and the tissue functions as a unit.

Muscle tissue consists of cells known as muscle fibers. These cells are elongated, and, like other cells, they contain nuclei and cytoplasm. The cytoplasm is known as sarcoplasm, and its plasma membrane is called the sarcolemma. The sarcolemmas of adjacent cells allow for communication and exchange of materials between the cells. Several cells form bundles, or fasciculi; and several of these form a muscle.

SMOOTH MUSCLES—Smooth muscle tissue is made up of elongated cells that lack transverse striations. The nucleus also is elongated. (265 X)

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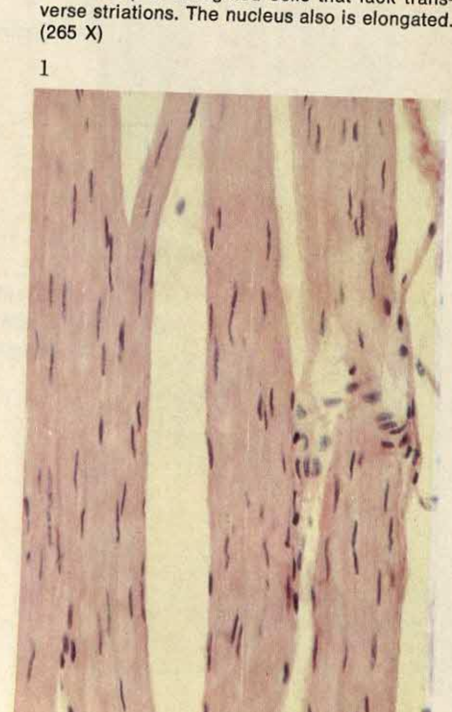


The contractile portions of muscle cells are elongated, proteinaceous structures known as myofibrils, which lie with their long axes parallel to the long axes of the muscle fibrils. Because of this, muscle fibers have faint longitudinal striations that are readily visible in stained preparations and, in some muscle tissues, are visible in fresh, unstained cells. Some muscle fibrils show obvious transverse striations, caused by the arrangement of protein molecules within the myofibrils.

Muscle tissue is classified according to its morphology, or form, and its function. If, under the microscope, the muscle fibers show transverse striations, the muscle tissue is classified as striated. Muscle without transverse striations is smooth muscle. Muscle tissue is also classified functionally. If the muscle's contraction can be controlled at will, it is a voluntary muscle; if it cannot, it is involuntary. Generally, smooth muscle tissue is associated with involuntary muscles and striated muscle tissue with voluntary muscles. An exception to this is the myocardium (cardiac or heart muscle), which, although striated, is involuntary.

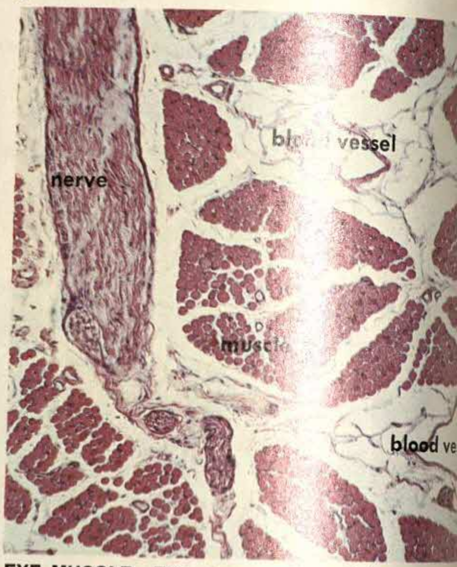
To summarize, three general types of muscle tissue exist: involuntary smooth muscle tissue; voluntary striated muscle tissue (skeletal muscle tissue); and involuntary striated muscle tissue (cardiac tissue or myocardium).

SMOOTH MUSCLE TISSUE

Smooth muscle tissue is found in the walls of many hollow organs of the digestive, respiratory, urinary, and reproductive systems and in the walls of the blood and lymph vessels. These are parts that are not generally under control of the will, and so the muscles are involuntary muscles.

Smooth muscle tissue consists of spindle-shaped cells. Each cell has a single rod-shaped nucleus located in a central position. In the cytoplasm, in addition to all the cellular organelles (mitochondria, Golgi apparatus, and central apparatus), numerous myofibrils run parallel to the long axis of the cell.

2



EYE MUSCLE—This cross section of the eye muscle shows several fasciculi and their individual cells. Two blood vessels and a nerve are also visible. (70 X)

Each muscle fiber is enveloped by connective tissue that consists of reticular and collagenous fibers. In a few places two smooth muscle fibers do contact each other, and here their plasma membranes fuse into a connection known as a nexus. Not all smooth muscle cells are supplied with nerve endings. Coordination of smooth muscle may be due in part to transmission of stimuli from muscle cell to muscle cell through the nexuses.

STRIATED MUSCLE TISSUE

Striated muscle tissue makes up all the voluntary skeletal muscles and some of the visceral muscles that are partly independent of the will, such as those of the tongue, pharynx, and esophagus.

Striated muscle fibers are thin, elongated cells with several nuclei located in the periphery of the sarcoplasm. The transverse striations of the cells are particularly noticeable even in unstained cells. The cross bandings indicate regularly repeating variations in structure and molecular content along the lengths of the contractile material.

CARDIAC MUSCLE

The cells of the myocardium (myocardium fibers) comprise the muscle of the heart. They have fewer myofibrils than striated muscle fibers, and for this reason they are lighter in color. An oval nucleus is located at the center of each fiber. Cardiac fibers also have transverse striations, and for this reason the heart muscle is classified as a striated muscle. It is included among the involuntary muscles because its contraction is not controlled by the will but is spontaneous.

Typical of cardiac muscle is the presence of unusually pronounced transverse bands called intercalated disks. These are the plasma membranes of adjacent cells. In some cases they are readily visible because the cytoplasm is unusually thick on the inner sides of the membranes of the two cells.

The myofibrils of cardiac tissue lie mostly in the periphery of the sarcoplasm. The central part of the cell does not have them, and sections of the centers of the cells appear to be clear and free of striations (Illustration 8).

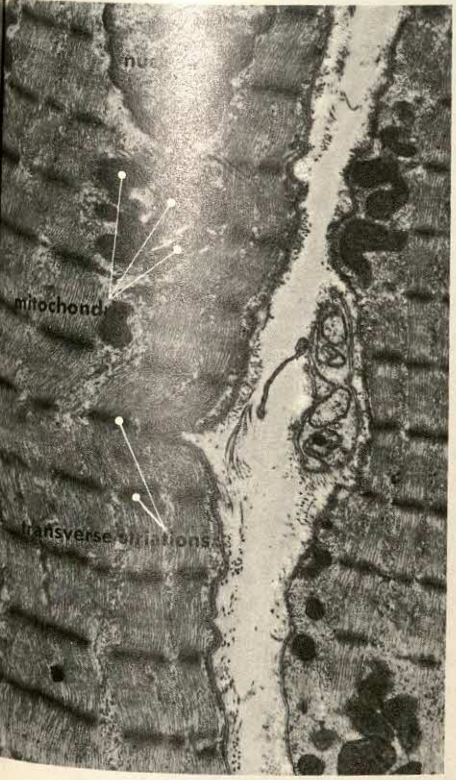
CONTRACTION OF MUSCLE

Although the three types of muscle tissue have different morphological characteristics, contraction in each is caused by contraction of its myofibrils. The mechanism of contraction is probably similar in all types of muscles, although the chemistry of smooth muscle contraction has not been thoroughly explored.

The myofibrils of skeletal muscles consist of repeating units known as sarcomeres. The narrow dark lines that are so obvious in striated muscles mark the ends of adjacent sarcomeres; these lines are called Z lines. Two Z lines can be seen in Illustration 4d, which shows a sarcomere in a relaxed state. A model of a relaxed sarcomere appears in Illustration 4c. The center of each sarcomere is occupied by a broad dark band, the A band, which has a lighter narrow zone, the H zone, in its center. A broad light band, the I band, extends from the A band of one sarcomere to the A band of the next sarcomere. The Z line occupies the center of an I band. The I band is so called because it is isotropic or singly refractive in polarized light. The A band is anisotropic or birefringent under polarized light.

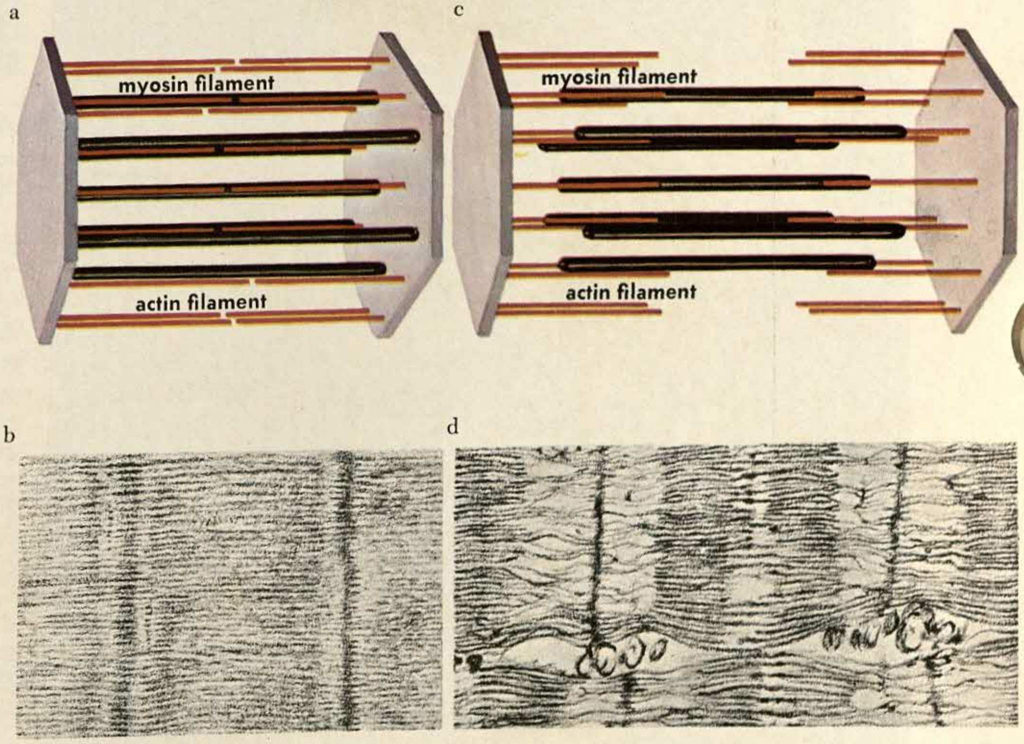
The sarcomeres consist of two types of protein: actin and myosin. Together these two proteins form the actomyosin complex that is the contractile portion of muscles. Myosin forms the thick filaments that run the length of the A band. Actin forms thinner filaments that extend from the Z line across the I band and, in a relaxed sarcomere, partly into the A bands. The arrangement of the actin and myosin is very exact. In a cross section through an A band (Illustration 6a and 6b), each myosin filament is seen to be surrounded by six actin filaments in a definite hexagonal arrangement. Each

3



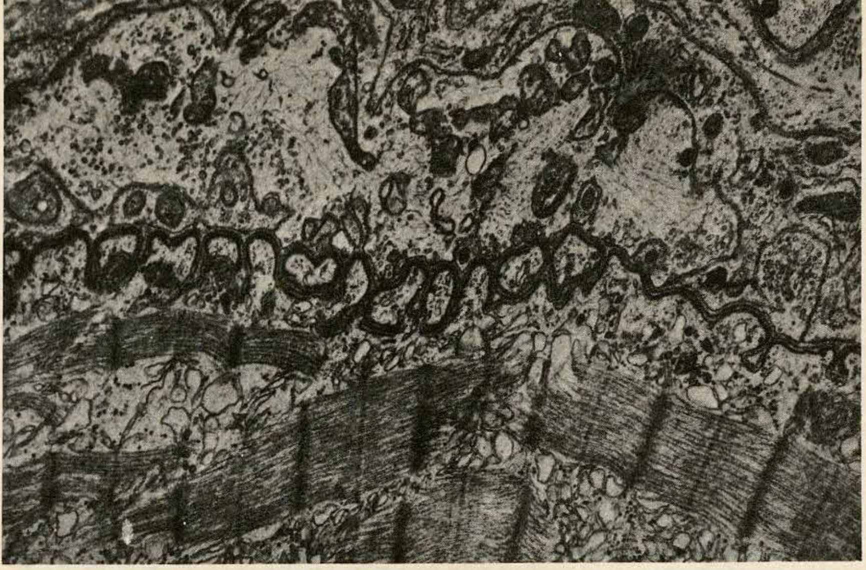
STRIATED MUSCLE—This electron micrograph reveals not only the dark transverse striations of the muscle but the fine longitudinal ones as well. Several mitochondria and part of a nucleus are visible.

4



MUSCLE CONTRACTION—In a contracted sarcomere (Illustration 4a), the actin filaments (red) have slid over the myosin filaments (black). In a relaxed sarcomere (Illustration 4c), the two types of filament have drawn away from each other. The hexagons represent Z bands. Electron micrographs of contracted and relaxed muscles are shown in Illustrations 4b and 4d respectively.

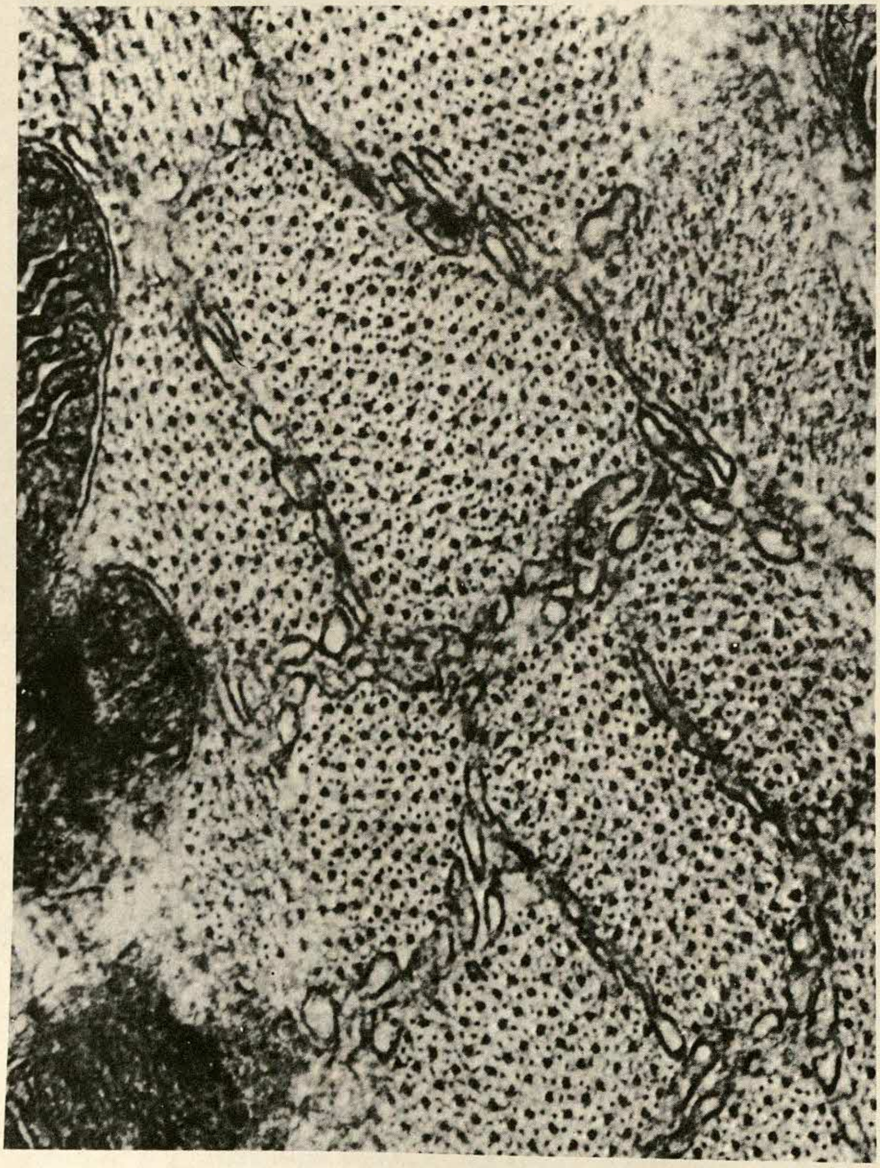
5



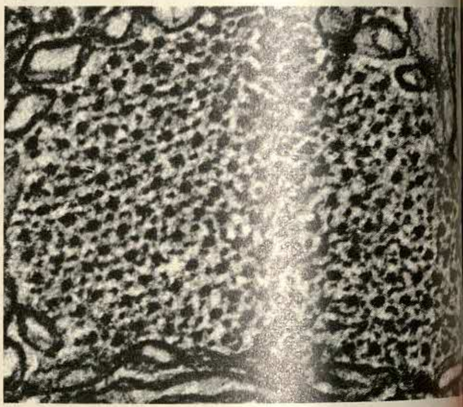
MOTOR END PLATE—A nerve ending (above) makes contact with a muscle cell. The connection is along a wavy surface. (27,000 X)

STRIATED MUSCLE IN CROSS SECTION—In Illustration 6a, each of the myosin filaments appears as a large black dot and is surrounded by six actin filaments that appear as fine dots. The wavy lines are sarcoplasmic reticulum. Illustration 6b shows the detail of one sarcomere. (90,000 X)

6a



6b



actin filament is surrounded by three actin filaments and three myosin filaments.

When a muscle contracts, the actin filaments slide over the myosin filaments, thus shortening the sarcomeres and, consequently, the myofibrils and the muscle fibers themselves. When a sarcomere contracts, the I band becomes smaller, for the myosin filaments approach the Z band (Illustrations 4a and 4b). At the same time the H zone also becomes smaller as the actin filaments at either end of the sarcomere approach each other in the center. When the sarcomere contracts to about 50 percent of its relaxed length, the I bands and H zone disappear. When the sarcomere relaxes, these areas reappear. The size of the A band does not change appreciably during contraction.

The exact mechanism of the sliding of actin filaments over the myosin filaments is not understood completely. Some electron micrographs show connections be-

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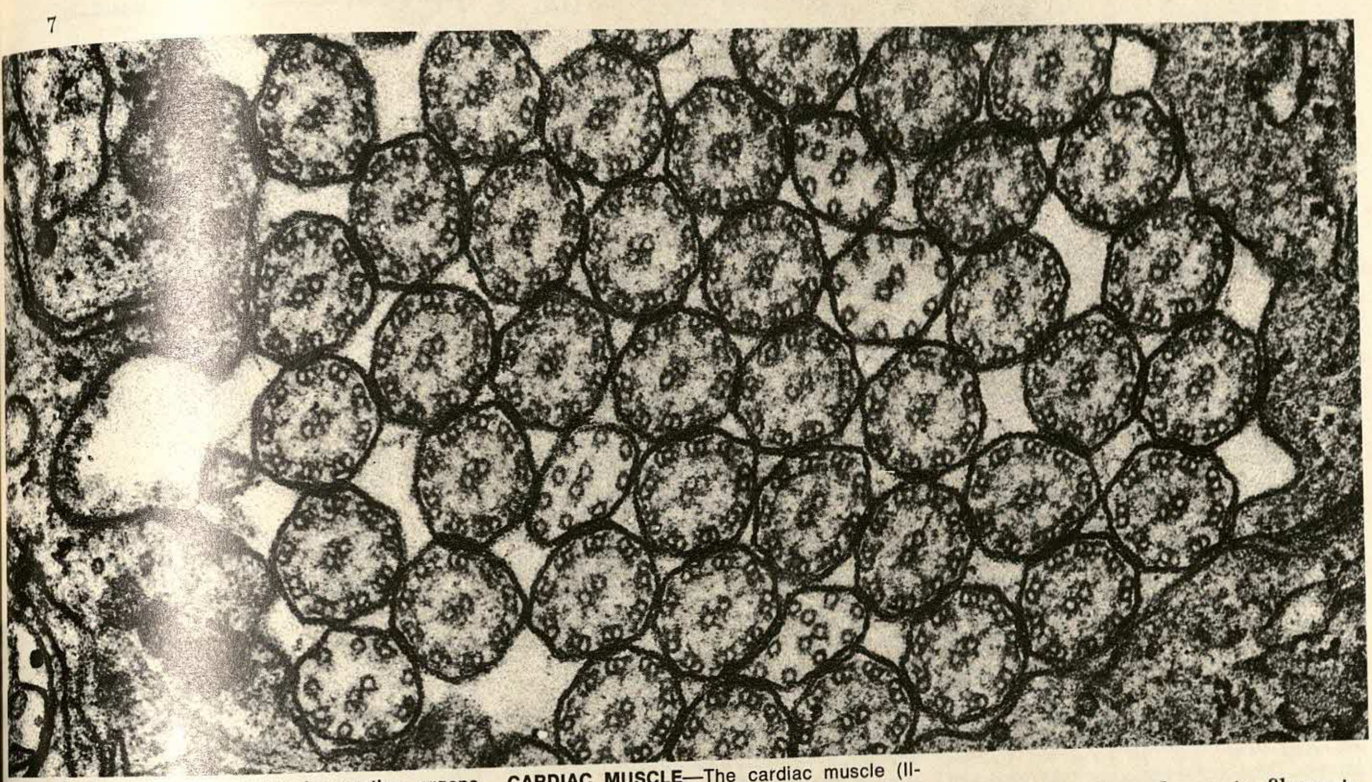
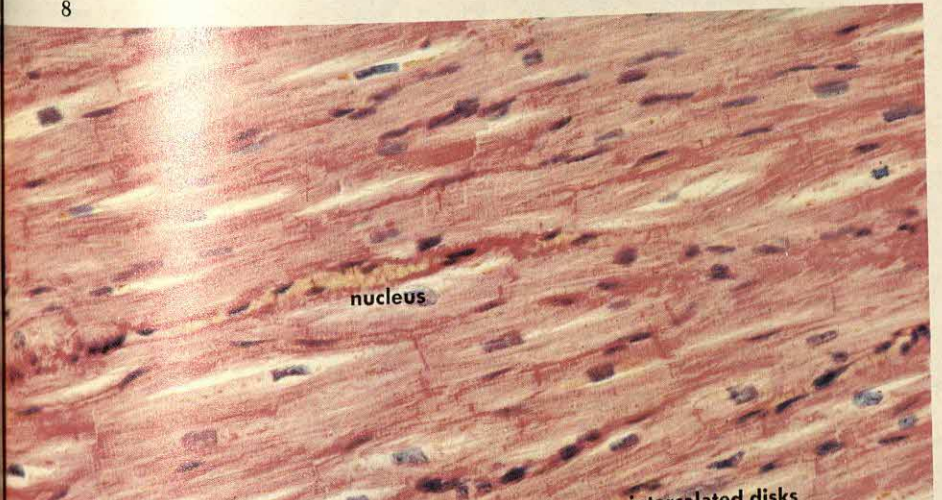


CILIA—Cilia are hairlike locomotive organs of some cells. They bend by contractions similar to muscular contractions. Each cilium has two simple fibrils surrounded by nine double fibrils. Illustration 7 shows a cross section of these cilia. (55,000 X)

CARDIAC MUSCLE—The cardiac muscle (Illustration 8) has transverse striations, and for this reason it is classified among the striated muscles. The cells have rod-shaped nuclei. The intercalated disks lie perpendicular to the main axis of the cells and parallel to the transverse striations. (300 X)

8



tween the actin and myosin filaments. This has led to the suggestion that the actin filaments may move in ratchet fashion with the connecting bridges forming, breaking, and reforming during the sliding process. Thus, neither the actin protein nor the myosin protein contracts, but the complex formed by the two does contract. Muscle cell preparations from which either actin or myosin has been removed chemically have no contractile properties.

The actomyosin complex cannot contract unless it has an energy supply. The energy used in contraction is supplied by the adenosine triphosphate (ATP) that is produced in the process of cellular respiration. Two types of respiration occur in muscle cells: aerobic respiration, which requires oxygen; and lactic acid fermentation, which does not. Aerobic respiration, which produces more ATP than does lactic acid fermentation, occurs in the sarcosomes (mitochondria). These organelles are usually located close to the myofibrils, and in very active muscles they are large and numerous. Lactic acid fermentation occurs in the sarcoplasm; although this process produces far less ATP than aerobic respiration, it supplements the ATP supply during prolonged exercise.

THE APPENDICULAR SKELETON

the bones of the arm and leg

The skeleton of the human body can be conveniently divided into two parts: the appendicular skeleton, which includes the bones of the arms and legs, and the axial skeleton, which includes the bones of the head, the vertebral column, the ribs, and the sternum (breastbone).

The bones of the arm are grouped as follows: (1) the pectoral girdle (or shoulder girdle), which consists of the clavicle and scapula; (2) the humerus of the upper arm; (3) the bones of the forearm (the radius and ulna); and (4) the bones of the hand, which include eight carpals, five metacarpals, and 14 phalanges. The total number of bones of each arm is 32.

The clavicle, or collarbone, is a long bone with a slight S-shaped curve. It extends from the sternum near the midline of the body to the humerus in the upper arm, and articulates with each of these bones.

The scapula, or shoulder blade, is a flat bone located in a dorsal position in the shoulder; it is triangular in form with its base at the top. The two clavicles, the two scapulas, and the sternum form an incomplete loop of bones in the upper part of the trunk. The loop is incomplete because the two scapulas do not articulate with each other in the dorsal area; here they are supported by the muscles in which they are embedded.

The upper arm has only one bone—the humerus—which extends the length of the upper arm. The upper end of the humerus has a rounded protuberance called the head, which articulates with a concave portion of the scapula. The joint formed by these two bones is a ball-and-socket joint that permits the upper arm to rotate freely in many directions.

The bones of the forearm—the radius and the ulna—extend approximately parallel to each other from the elbow to the wrist. The ulna lies toward the outside or the little-finger side of the arm. The articulation of the radius and the ulna with the humerus at the elbow forms a hinge joint. The forearm can move through an angle of about 180° but in one plane only. The freedom of movement at the elbow thus is less than that of the shoulder.

The bones of the hand are grouped into the carpus, metacarpus, and the bones of the fingers. The carpus consists of the eight bones of the wrist, which lie in two transverse rows, each row having four short bones. From the thumb side toward the little-finger side, those in the upper row are the scaphoid, lunate, triangular, and pisiform bones; in the lower row they are the trapezium, trapezoid, capitate, and hamate bones. The upper group articulates with the radius and ulna, while the lower group articulates with the upper group and with the bones in the palm of the hand. The eight small carpals give the wrist great flexibility.

The metacarpus is composed of five long metacarpal bones that extend across the palm. They radiate from the wrist, each metacarpal reaching to the base of one finger. The metacarpals articulate with the lower group of carpal bones and with the bones of the fingers.

The finger bones are long bones called phalanges (singular, phalanx). There are three on each finger, with the exception of the thumb, which has only two.

The bones of the leg are classified in groups that correspond to those of the arm: (1) the pelvic girdle (or hip girdle), which is composed of two hipbones and two bones of the vertebral column—the sacrum and the coccyx; (2) the femur of the thigh; (3) the patella of the knee; (4) the bones of the lower leg—the tibia and the fibula; and (5) the bones of the feet, which include seven

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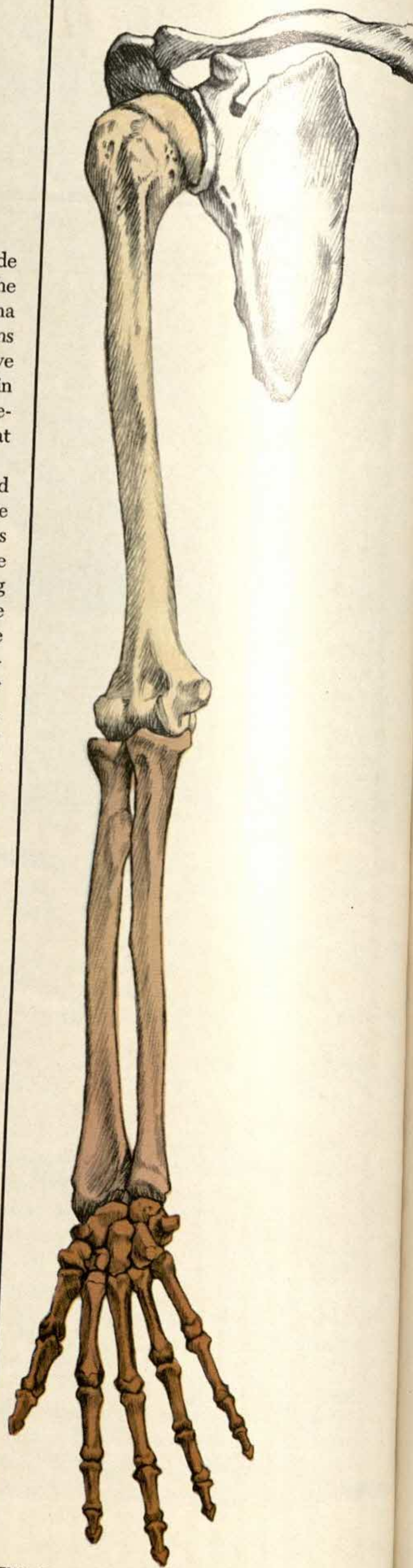
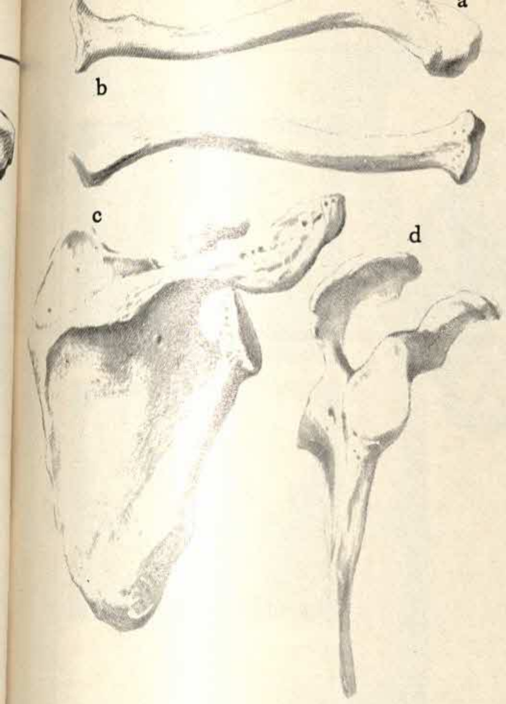


THE BONES OF THE UPPER ARM

2

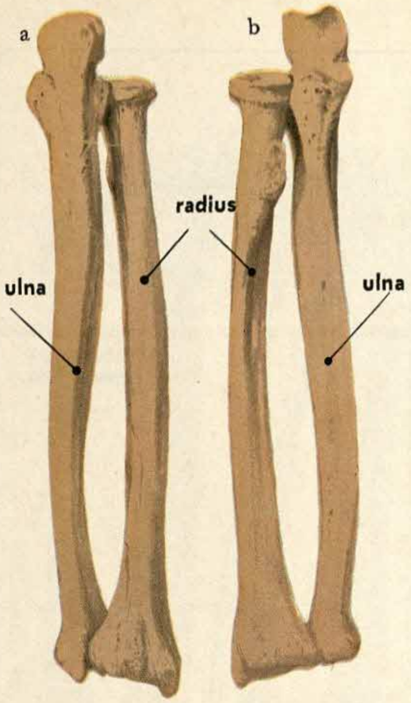


THE BONES OF THE SHOULDER—The clavicle is a long bone lying horizontally in the upper anterior region of the body. It is shown in Illustration 2a from below and in Illustration 2b from above. The clavicle articulates with the scapula, a flat, triangular bone that lies in the dorsal part of the shoulder. The scapula is shown from the front in Illustration 2c and in profile in Illustration 2d.

tarsals, five metatarsals, and 14 phalanges.

Each hipbone is the result of the fusion of three bones: the ilium, the ischium, and the pubis. These three bones are separate in children but are fused in adults. Where the three bones meet there is a rounded depression, the acetabulum, which articulates with the femur. The pelvic girdle forms a complete ring. Anteriorly, the two hipbones articulate with each other in a slightly movable joint, the pubic symphysis. Posteriorly, the two hipbones articulate with the sacrum of the vertebral column. The opening in the center of the pelvic girdle is larger in women than in men; during birth the baby passes through this opening, which enlarges somewhat at this time because the pelvic joints and ligaments relax.

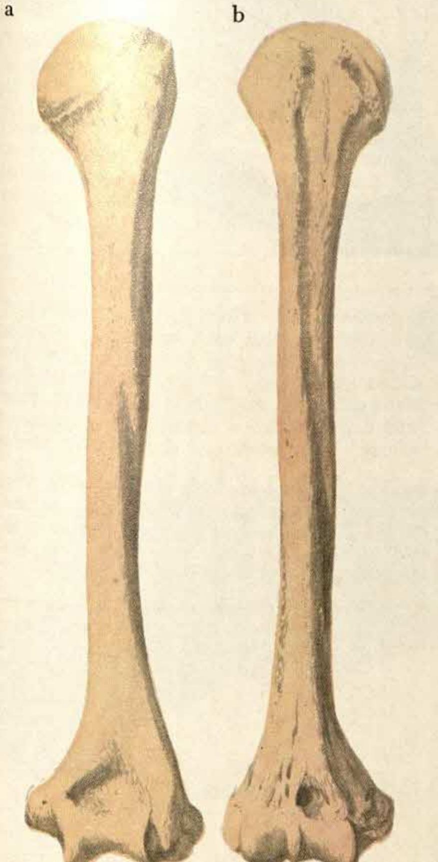
4



THE SKELETON OF THE FOREARM—The two long bones of the forearm, the ulna and the radius, lie parallel to each other. The ulna is located on the little-finger side of the arm and the radius on the thumb side. They are united at their extremities. The dorsal view of these bones is shown in Illustration 4a, the ventral view in Illustration 4b. They have a lengthwise hollow in the shaft.

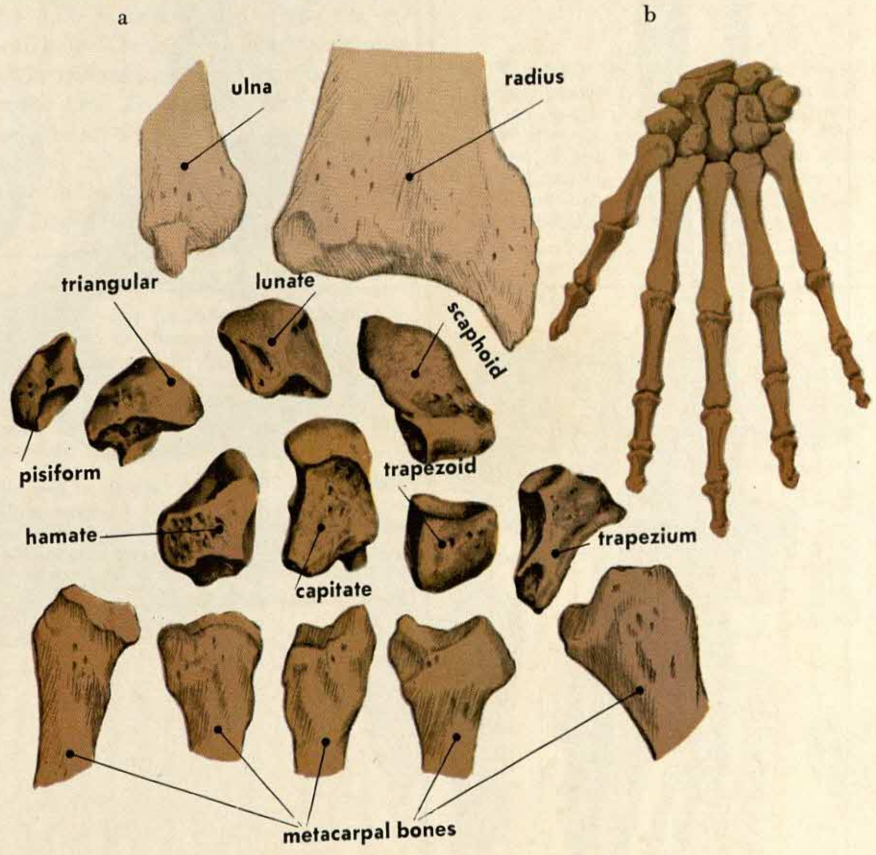
3

THE HUMERUS—The humerus is the long bone of the upper arm. The upper end of this bone articulates with the two bones of the forearm, the radius and ulna. The dorsal surface of the humerus is shown in Illustration 3a and the ventral surface in Illustration 3b.



5

THE BONES OF THE HAND—The 27 bones of the hand (Illustration 5b) can be divided into three groups: the carpus (bones of the wrist), the metacarpus (bones of the palm), and the phalanges (bones of the fingers). The carpus (Illustration 5a) is made up of eight bones in two rows: the scaphoid, lunate, triangular, and pisiform; and the trapezium, trapezoid, capitate, and hamate. The metacarpus consists of five metacarpal bones. The thumb has two phalanges; the other fingers have three.



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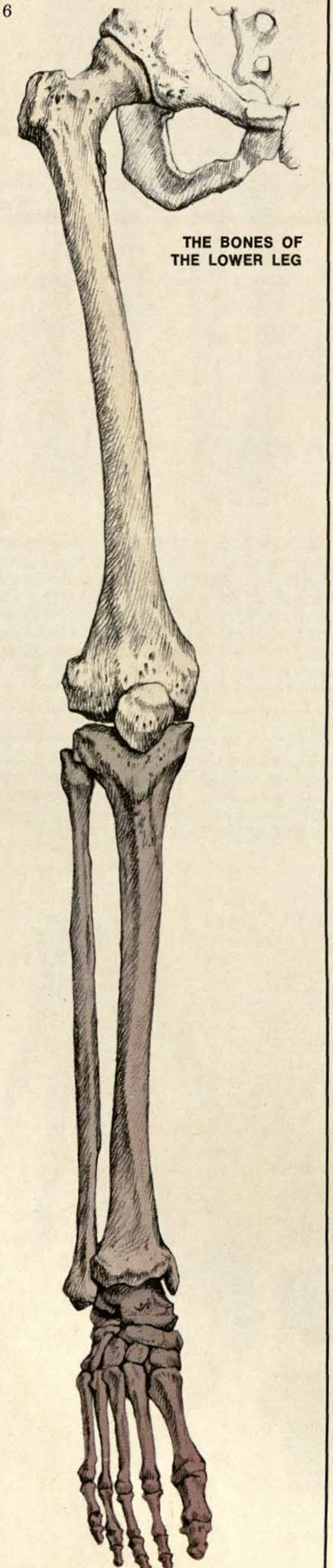
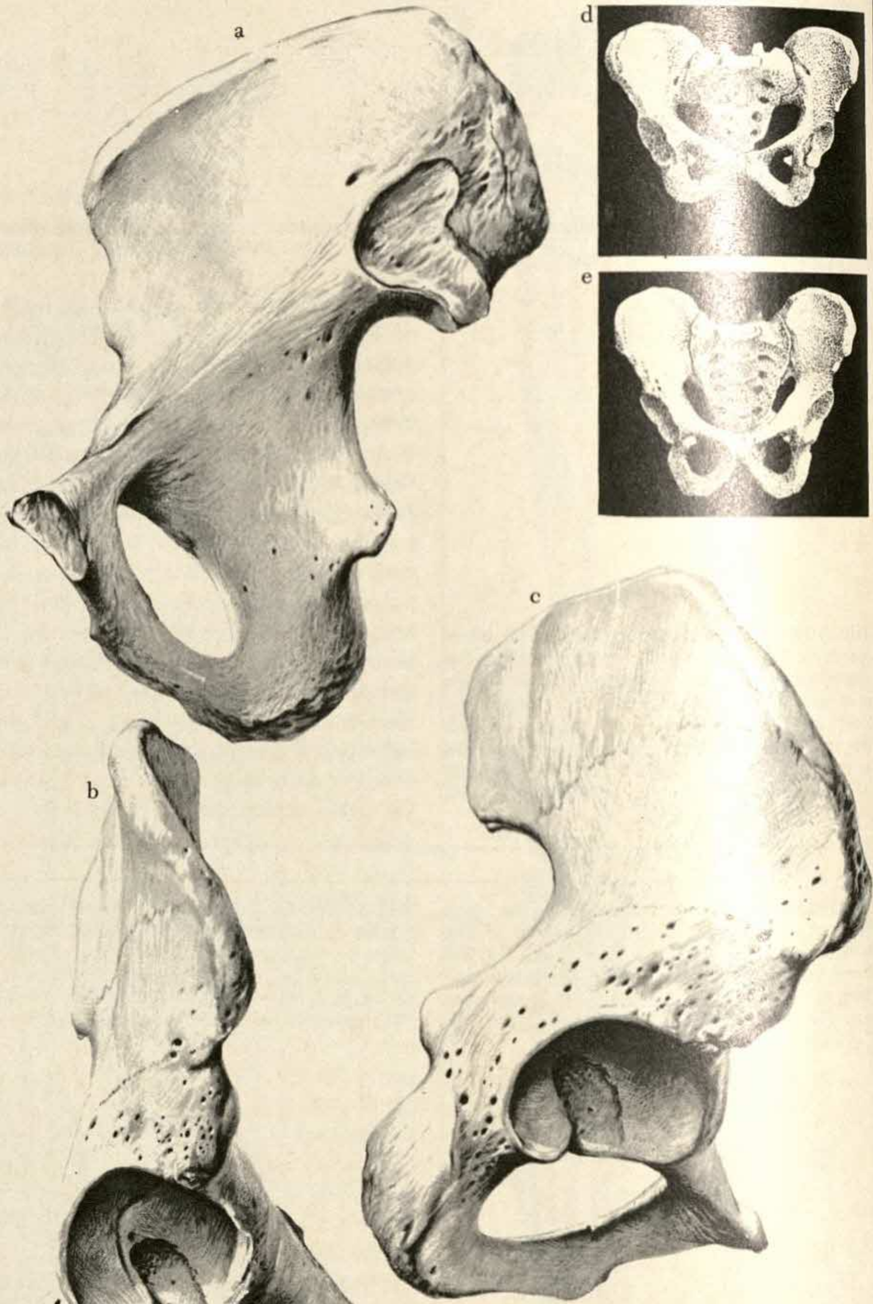


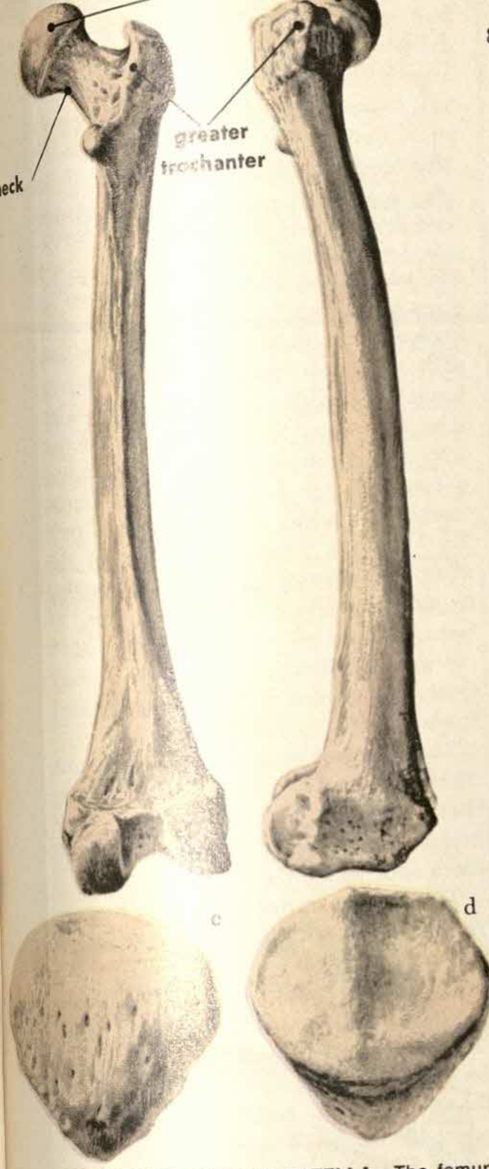
THE BONES OF THE LOWER LEG

7



THE PELVIS—The pelvis consists of two hipbones and the sacrum and the coccyx of the vertebral column. The internal surface of the hipbone is shown in Illustration 7a, a view from its anterior extremity in Illustration 7b, and its external surface in Illustration 7c. The opening between the two hipbones of the female pelvis (Illustration 7d) is larger than that in the male pelvis (Illustration 7e); the larger opening facilitates childbirth.

8



The skeleton of the thigh consists of a single bone—the femur, or thighbone. It is a long bone with a hemispherical head that articulates with the acetabulum of the hipbone. This forms another ball-and-socket joint that allows great freedom of movement.

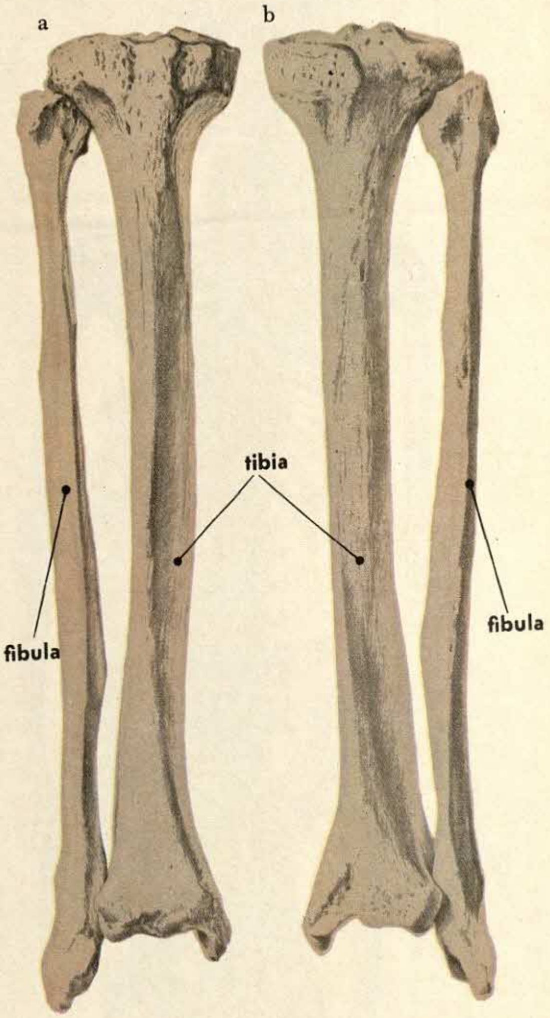
The patella, or kneecap, has no counterpart in the skeleton of the arm. This small bone lies in the front of the knee joint and articulates with the lower end of the femur.

The two long bones of the lower leg are the tibia and fibula. The tibia is located toward the center of the body, the fibula toward the outside. These articulate with the femur at the knee, which, like the elbow, is a hinge joint.

The bones of the foot are divided into the tarsus, metatarsus, and the bones of the toes. The tarsus consists of seven tarsal bones arranged in two groups composed of two and five bones respectively. The talus and the calcaneus make up the first of the two groups. The talus, or anklebone, articulates with the tibia and fibula. The largest of the tarsal bones is the calcaneus, which is the heel bone. The second group includes the navicular, the three cuneiform bones, and the cuboid bone. The five long metatarsal bones of the metatarsus extend from the tarsals to the toes. The tarsals and metatrasals form the arch of the foot. Like the fingers, the toes have three phalanges each except the large toe, which has only two phalanges.

THE FEMUR AND THE PATELLA—The femur, or thighbone, lies in the upper leg. Its upper end articulates with the hipbone and its lower end with the tibia of the lower leg and patella (kneecap). The posterior surface of the femur is shown in Illustration 8a and a lateral surface in Illustration 8b. The anterior surface of the patella is shown in Illustration 8c and its posterior surface in Illustration 8d.

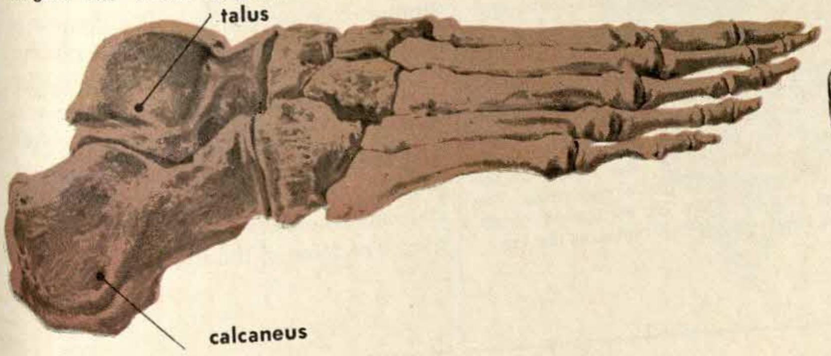
9

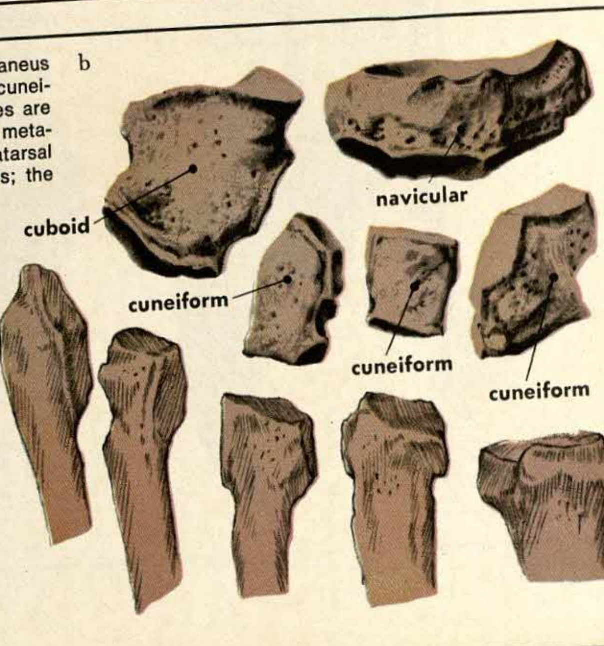


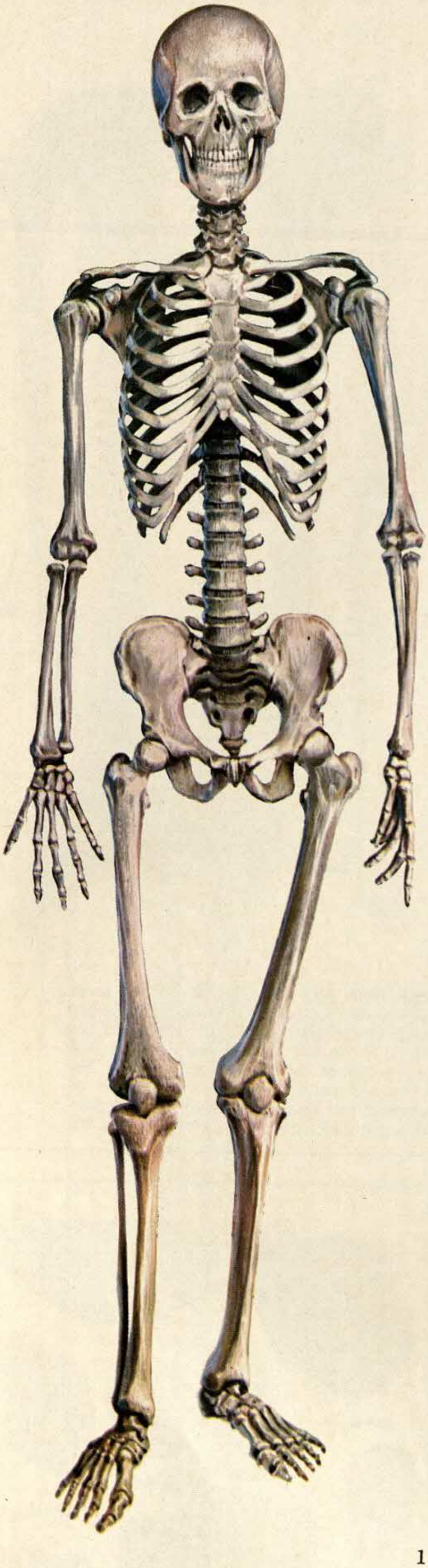
THE TIBIA AND THE FIBULA—In the lower leg are two parallel long bones. The tibia lies toward the median line of the body, and the fibula is situated toward the exterior. The upper end of the tibia articulates with the femur and patella. The anterior surfaces of the tibia and fibula are shown in Illustration 9a, and the posterior surfaces in Illustration 9b.

10

THE BONES OF THE FOOT—The 26 bones of the foot (Illustration 10b) articulate with one another and form the arch of the foot, which permits the foot to sustain the weight of the body. The bones of the foot are divided into three groups: the tarsus, metatarsus, and phalanges. The tarsus is composed of seven bones: the talus (anklebone), the calcaneus (heel bone), the navicular, the three cuneiforms, and the cuboid. The smaller bones are shown in detail in Illustration 10b. The metatarsus is composed of five thin metatarsal bones. The large toe has two phalanges; the other toes have three.







1

THE HUMAN SKELETON—The framework of the human body consists of 206 bones that articulate with each other. On the dorsal median line of the body is the vertebral column, which supports the skull, the ribs, and the bones of the pectoral girdle and arms. The vertebral column rests on the pelvic girdle, which is supported by the bones of the leg.

THE AXIAL SKELETON

the vertebral column and the pectoral and pelvic girdles

The human body is supported by a bony skeleton that is divided into two parts: the axial skeleton and the appendicular skeleton. The former includes the bones of the head, the vertebral column, the ribs, and the sternum.

The vertebral column (sometimes called the backbone) is a vertical row of 33 bones called vertebras. These bones vary somewhat but all are built on the same general pattern. The typical vertebra has a very thick ventral portion, the body. From the dorsal side of the body extends the neural arch. The vertebral foramen is the opening between the body and the neural arch. The vertebral canal is a continuous tube formed by the vertebral foramina of all the vertebras in the column. The vertebras protect the spinal cord, which is contained by this canal.

The vertebra has seven processes. Two transverse processes occur at either side of the neural arch, while a third—the spinous process—takes the form of a dorsal prolongation of the neural arch. Four articular processes articulate with other vertebras, two with the vertebra above and two with the vertebra below.

The vertebras are divided into different groups according to the regions of the body in which they are located. Seven cervical vertebras are found in the neck region, twelve thoracic vertebras in the chest region, five lumbar vertebras in the abdominal region, five sacral vertebras, and four coccygeal vertebras at the base of the vertebral column.

The cervical vertebras have the basic characteristics of the typical vertebra described above, but they differ in some respects. The terminal portion of the spinous process is forked, and each transverse process has an opening, the transverse foramen, through which spinal nerves and blood vessels pass. The first and second cervical vertebras have special names—the atlas and the axis. The atlas has no body, but there is an arch known as the ventral arch, which is linked with the dorsal arch by means of two formations called the lateral masses. The skull articulates with the atlas, and the atlas articulates with the axis. On its upper surface, the body of the axis has a toothlike process, the dens, which projects into the vertebral foramen of the atlas. This permits the skull and the atlas to rotate on the axis when the head is turned. The other cervical vertebras have the characteristics described above; they gradually increase in size as they descend to the thoracic vertebras.

The twelve thoracic vertebras support the twelve pairs of ribs of the thorax; these vertebras differ from other vertebras in having articular facets, small surfaces with which the ribs articulate.

The lumbar vertebras are the largest vertebras. They have no articular facets and no transverse foramina.

The sacrum consists of five fused vertebras. The coccyx usually consists of four, but there may be five or only three. The coccygeal vertebras are rudimentary, and the last three are small and barely recognizable as vertebras.

The joints between adjacent vertebras are filled with disks of fibrous cartilage. These disks are "shock absorbers" that prevent the vertebras from striking or rubbing against each other.

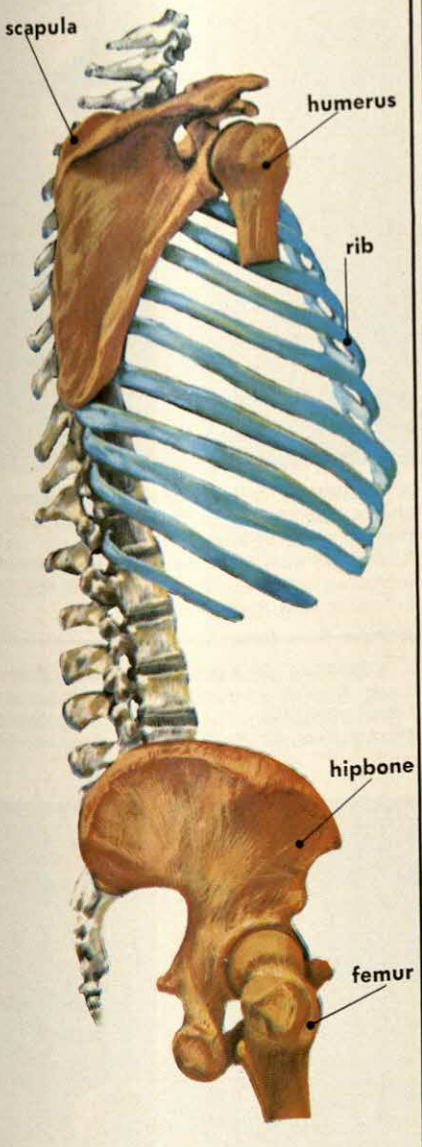
The vertebral column is not perfectly straight but has a slight S-curve that provides strength. The joints between the vertebras are slightly movable, permitting the body to bend forward and from side to side.

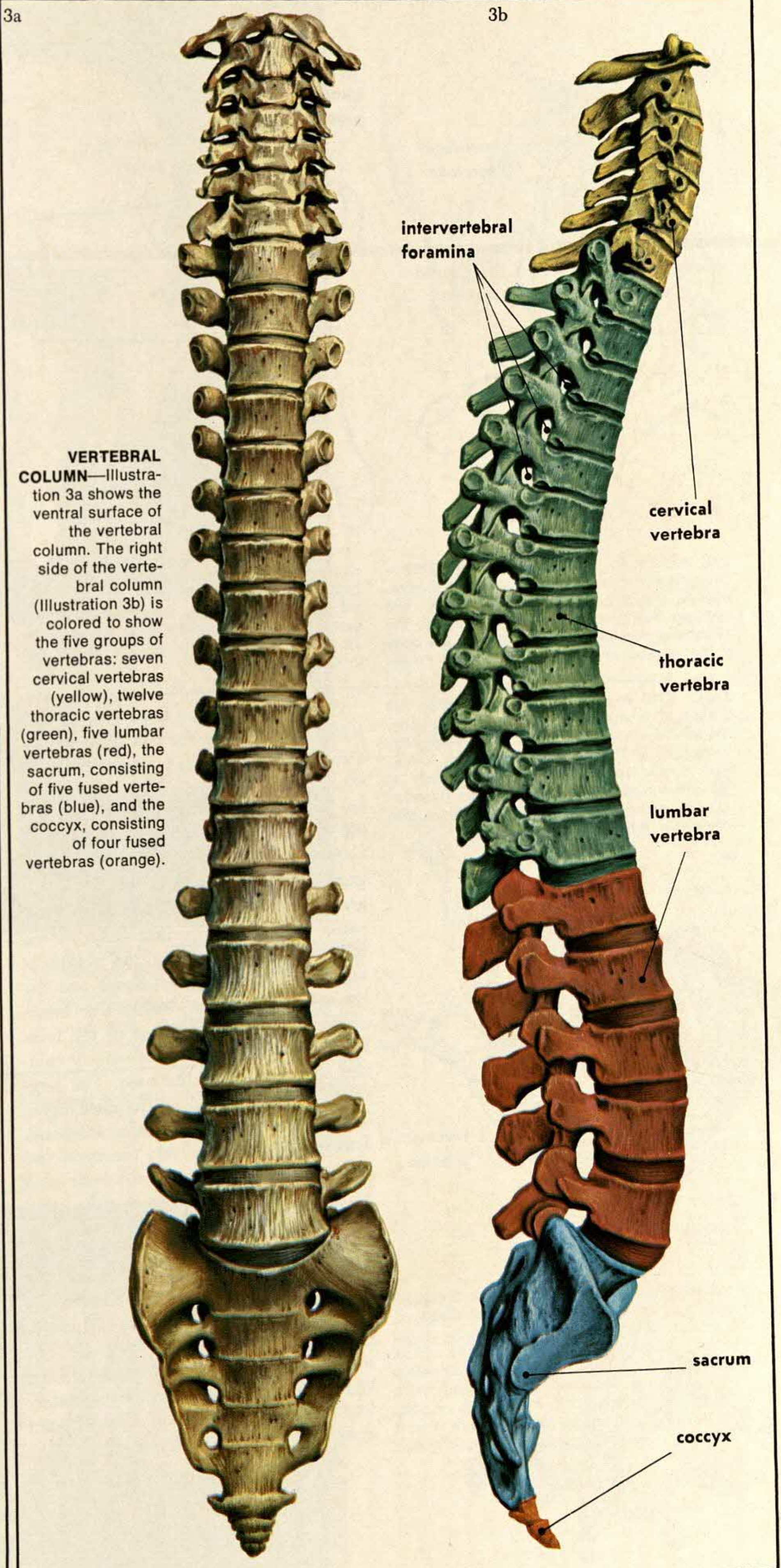
The skeleton of the thorax, which forms a protective cage around the heart and lungs, consists of the twelve thoracic vertebras, twelve pairs of ribs, and the sternum (or breastbone). The sternum is a single, flat bone located in a median ventral position in the thorax. The upper part is the manubrium; the middle and largest part is the body; and the lowest and smallest part is known as the xiphoid process. On the lateral margins of the sternum are notches with which the cartilages of some of the ribs articulate.

The ribs are flat bones, narrow and quite elongated. The dorsal end of each rib articulates with one of the thoracic vertebras. The rib curves around the thorax and approaches the sternum. None of the ribs, however, articulates directly with the sternum. The upper seven pairs of ribs, known as true ribs or vertebrosternal ribs, articulate with the sternum by means of cartilage. The eighth, ninth, and tenth, called the vertebrochondral ribs, are each united by their cartilages to the cartilages of the preceding rib. The eleventh and twelfth pairs, the floating or vertebral ribs, have no ventral attachment. The intervals between the ribs are called intercostal spaces, from the Latin *inter* (between) and *costa* (rib).

SKELETON OF THE TRUNK

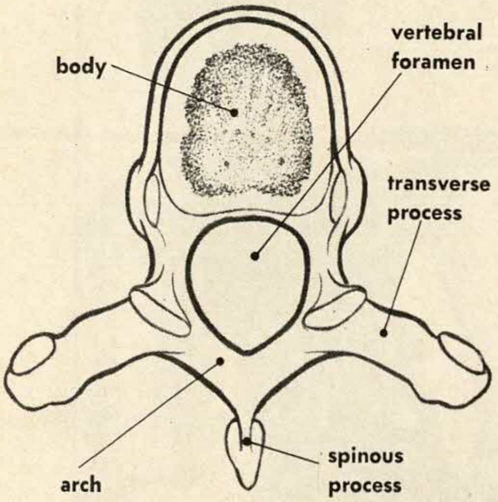
2



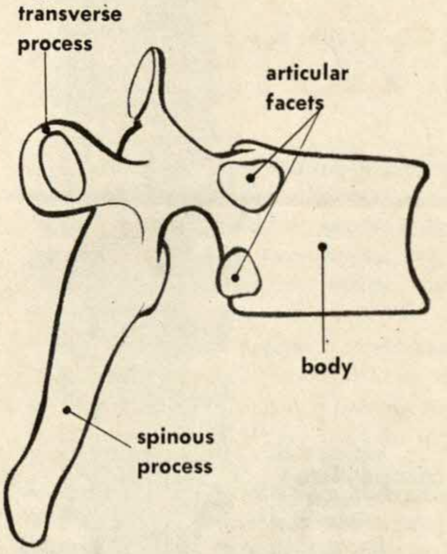


VERTEBRAL COLUMN—Illustration 3a shows the ventral surface of the vertebral column. The right side of the vertebral column (Illustration 3b) is colored to show the five groups of vertebras: seven cervical vertebras (yellow), twelve thoracic vertebras (green), five lumbar vertebras (red), the sacrum, consisting of five fused vertebras (blue), and the coccyx, consisting of four fused vertebras (orange).

4a



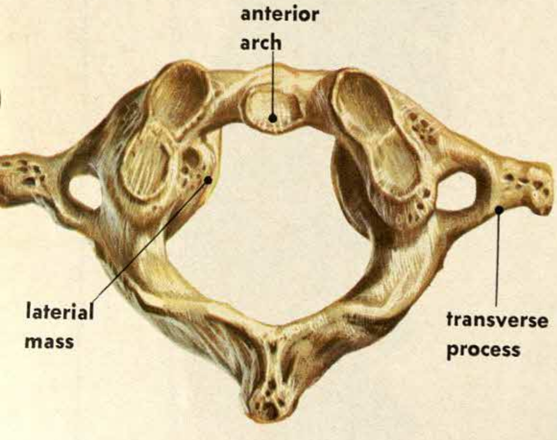
4b



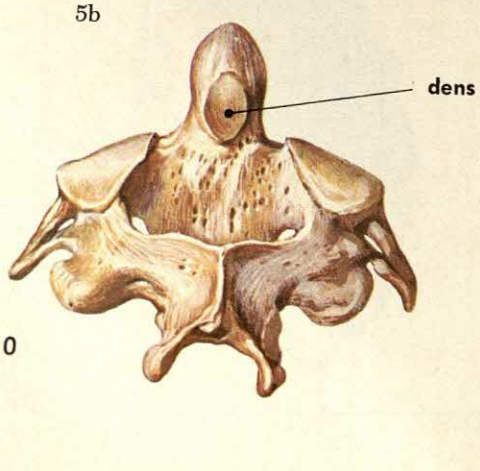
THE PARTS OF A THORACIC VERTEBRA—The vertebra is shown from above in Illustration 4a and in profile in Illustration 4b. The vertebra has the form of a bony ring; the cylindrical ventral portion constitutes the body of the vertebra; the dorsal portion is the neural arch. Surrounded by the body and the neural arch is the vertebral foramen through which the spinal cord extends. Two transverse processes branch from the sides of the arch; another, the spinous process, is a dorsal prolongation of the arch.

ATLAS AND AXIS—The atlas (Illustration 5a) is the first cervical vertebra. Instead of a body, this vertebra has the anterior (or ventral) arch connected to the dorsal arch by two formations known as lateral masses. The body of the axis, the second cervical vertebra (Illustration 5b), has a projection called the dens that articulates with the atlas.

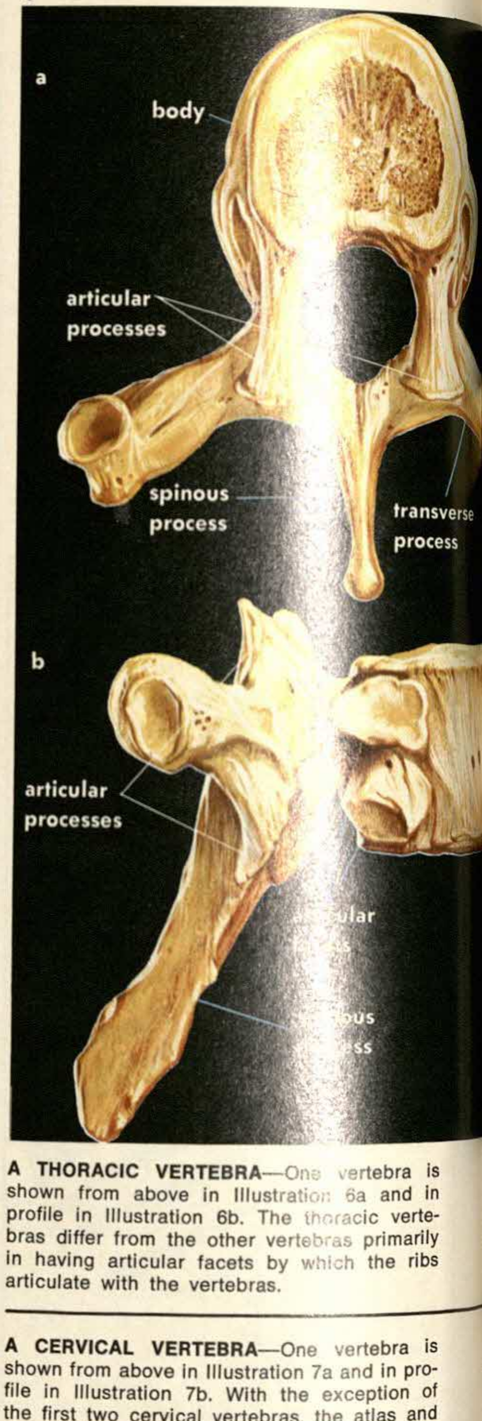
5a



5b



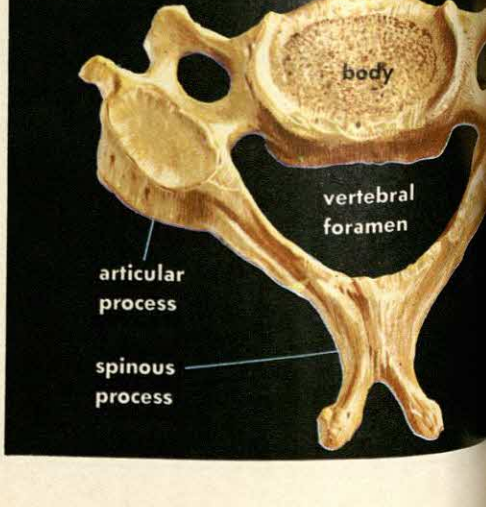
The skeleton of the head is quite different from that of the rest of the body. The hard skull forms a protective solid shell for the soft brain. Many bones join to form the skull. The largest ones—fitting over the back, top, and forehead—are flat and slightly rounded. They grow together after birth. Orbits, which are cuplike bones, hold and protect the eyes, leaving an opening only in the front. Bones also protect the organs of hearing. Some of these bones are the tiniest in the body. Inside the bones of the face, including those of the forehead and cheek, are the sinuses—air cavities connected with the nose. The largest of these cavities is in the cheekbone. The next in size is in the forehead. Smaller cavities open into the back and sides of the nose. Except for bone next to the skull, the nose is mostly cartilage. The bones of the upper and the lower jaw have small sockets into which the teeth fit. The teeth are also part of the skeleton. All the head bones except for the jawbones are fitted together by fibrous joints that do not move. The lower jaw is fastened to the upper jaw by a looser joint immediately in front of the ears. This kind of joint can move in several directions.



A THORACIC VERTEBRA—One vertebra is shown from above in Illustration 6a and in profile in Illustration 6b. The thoracic vertebras differ from the other vertebras primarily in having articular facets by which the ribs articulate with the vertebras.

A CERVICAL VERTEBRA—One vertebra is shown from above in Illustration 7a and in profile in Illustration 7b. With the exception of the first two cervical vertebras, the atlas and

7a



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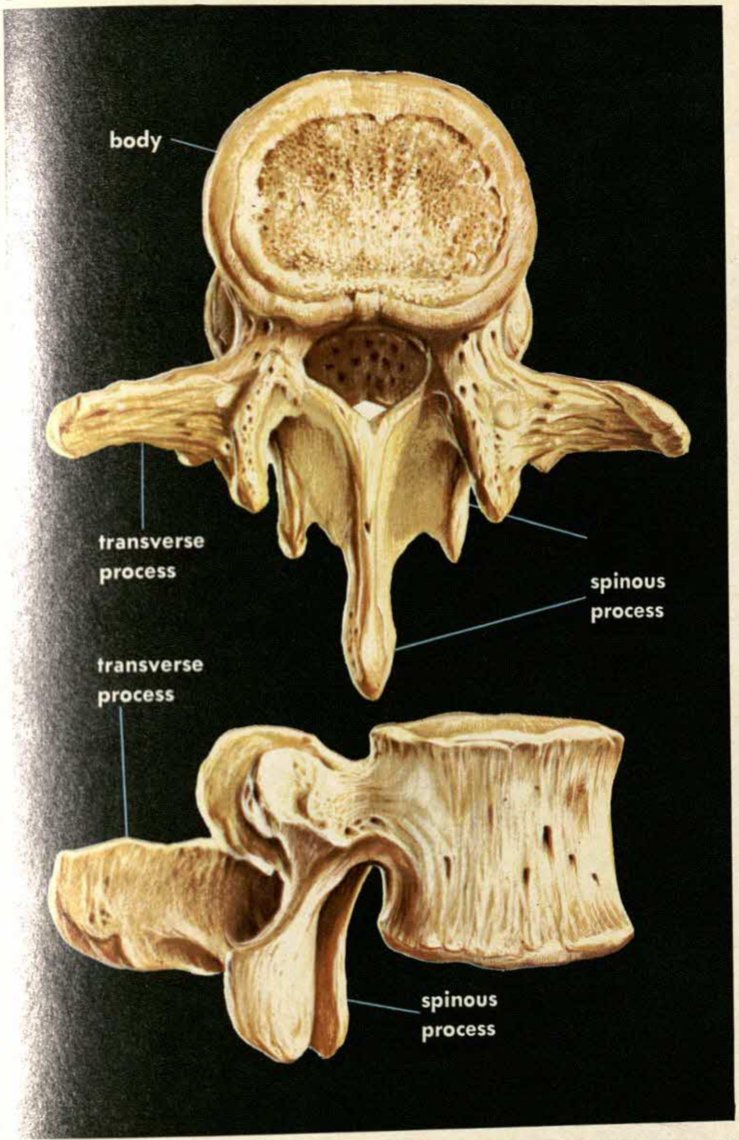
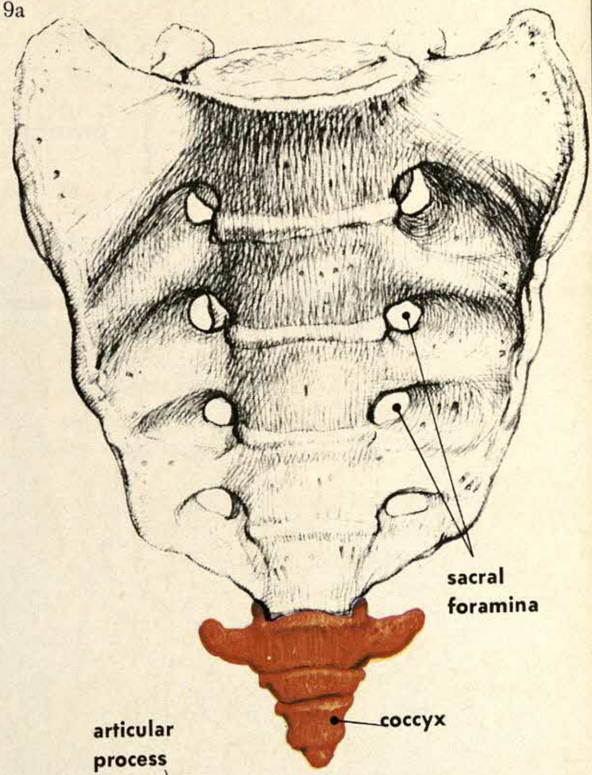
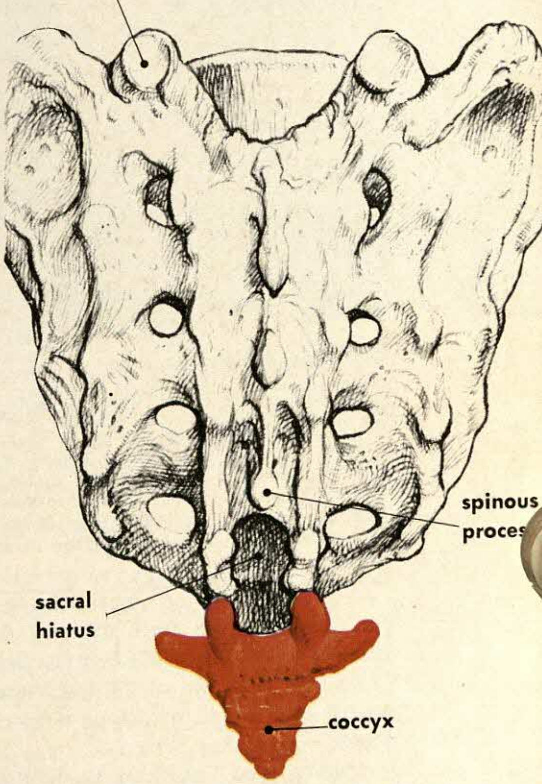


9a



9b



A LUMBAR VERTEBRA—The lumbar vertebra (Illustration 8a from above, Illustration 8b in profile) has a very thick body. The body has no facets, and the transverse processes have no transverse foramina.

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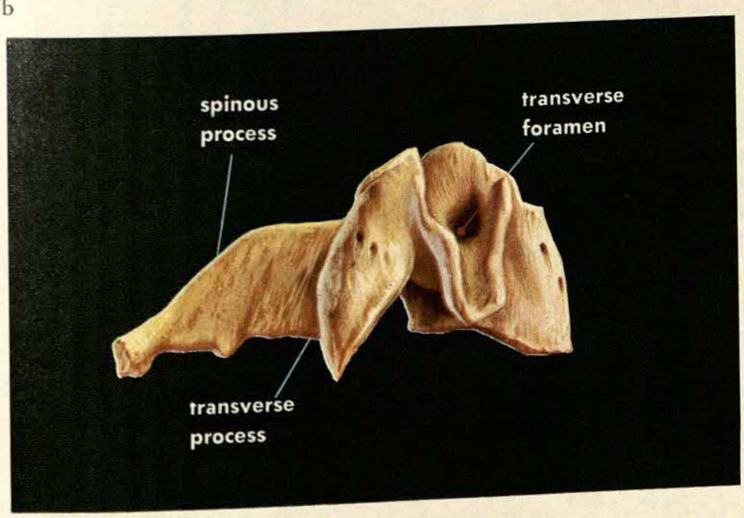
the axis, which present particular characteristics, a cervical vertebra has a small body elongated transversely, a triangular vertebral foramen, a forked spinous process, and two transverse processes. Each transverse process is perforated by a transverse foramen that contains spinal nerves and blood vessels.

7b

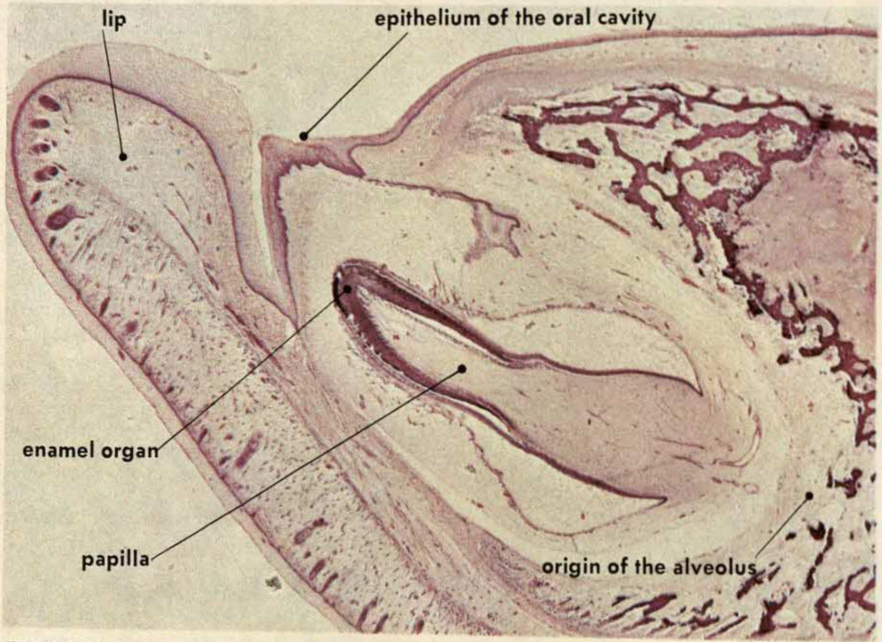


SACRUM AND COCCYX—On the ventral surface (Illustration 9a), the sacrum has four transverse reliefs that mark the line of fusion of its five vertebras. At each side are four sacral foramina, produced by the fusion of the transverse processes of adjacent vertebras. The coccyx consists of four fused rudimentary bones. Illustration 9b shows the sacrum and coccyx from the opposite side.

TEETH | primary instruments of digestion

Teeth—those hard and resistant organs—are used chiefly to grasp, cut, and grind food. In most vertebrates teeth are situated in the alveoli, which are cavities in the maxillary and mandibular bones. Because not all animals eat the same kind of food, they have diverse types and numbers of teeth. Carnivorous animals, for example, need teeth different from those of animals that feed on roots, fruits, or leaves. The form of the teeth, therefore, is appropriate to the type of nourishment.

1



THE DEVELOPMENT OF A TOOTH—The illustration shows a tooth bud or tooth germ in a dog. The dark enamel organ caps the dental papillum. The first tooth bud appears generally as a thickening in the epithelium of the mucosa that then sinks into the connective tissue. Each tooth germ is shaped like an inverted bowl. The epithelial cells at the inside of the bowl become specialized as ameloblasts; these are part of the enamel organ, and they produce the enamel. The outermost elements of the papilla become specialized as odontoblasts, which form the dentin; the innermost part forms the pulp of connective tissue, containing blood vessels and nerves. The pulp cavity usually remains open at the bottom. The final form of the tooth depends on the form of the enamel organ.

Invertebrates, particularly mollusks, annelids, and arthropods, have horny structures that, for their appearance, position, and function, must be considered teeth. Among the vertebrates, few animals are without bony teeth (birds are one exception, for they have no teeth). If an animal has teeth that are all alike, it is said to have homeodont dentition; if it has dissimilar types of teeth, it is said to have heterodont dentition. Heterodont teeth are classified as incisors, canines, premolars, and molars (the type of dentition typical of most mammals).

THE FORM OF BONY TEETH

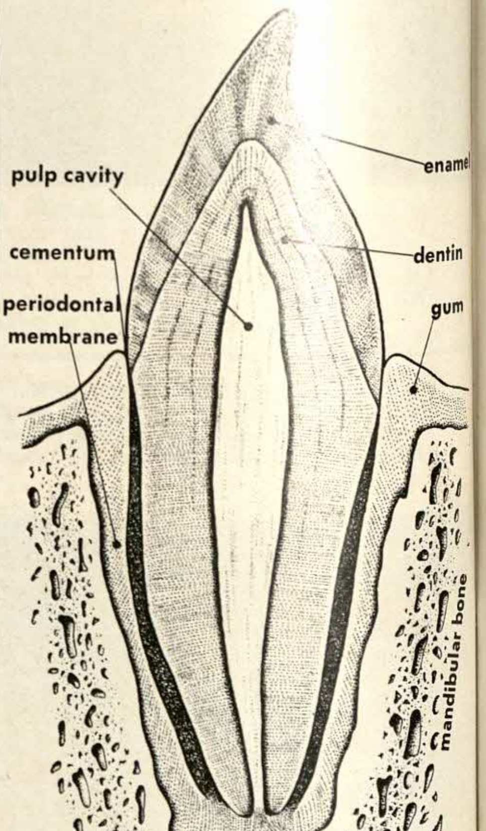
Human beings have two curved rows of teeth called dental arches, one in the upper jaw and the other in the lower. Adults usually have sixteen teeth in each dental arch.

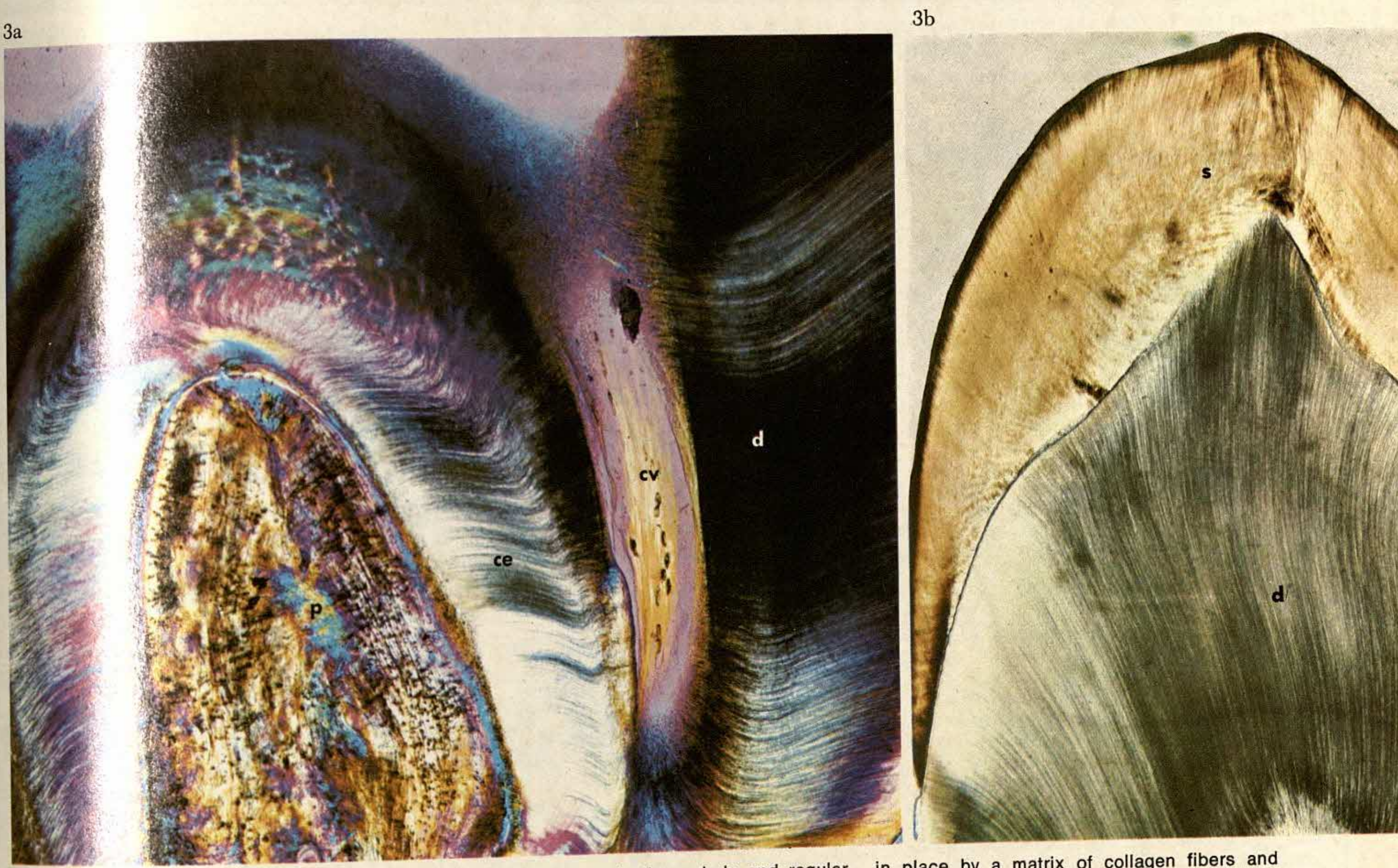
Each tooth is divided into three parts: crown, neck, and root. The dental crown is that part of the tooth that extends above the gum and into the mouth cavity. The neck is surrounded by the gum, and the root penetrates into the bone of the jaw.

The shape of the crown varies with the type of tooth, as well as with the animal that possesses it. Incisors—whose main functions are biting and cutting—have crowns that resemble chisels, with

MATURE TOOTH—In a tooth that has completed its development and differentiation, the solid and extremely resistant enamel that covers the tooth is nearly all calcium phosphate. Beneath the enamel is a layer of dentin, a hard substance that resembles bone. The pulp in the pulp cavity is formed of connective tissue rich in blood vessels and nerves. The odontoblasts, which produce dentin, line the pulp cavity. The cementum surrounds the dentin of the root, and the periodontal membrane occupies the space between the cementum and the bone.

2





A TOOTH UNDER THE MICROSCOPE—Illustration 3a is a longitudinal section of a tooth under a light-polarizing microscope, showing the papilla **p**, the pulp cavity **cv**, the cementum **ce**, and the rather thick stratum of dentin **d**. In Illustration 3b, a longitudinal section is shown under a compound microscope. High magnification reveals the orderly and regular structure of the dentin **d** and the layer of enamel **s** that covers it. Dentin, like bone, consists of about 72 percent inorganic salts and 28 percent organic compounds. This material is organized into fine tubules that extend from the pulp to the enamel. The tubules are held in place by a matrix of collagen fibers and calcified ground substance. Enamel has a compact structure formed of hexagonal prisms (with a diameter of 6 μm), united in bundles. Enamel, which is derived from epithelial tissue, is the hardest and most resistant type of tissue that exists in the animal organism.

two flat surfaces and a thin cutting edge. Man has eight incisors, four at the center of the upper dental arch and four at the center of the lower.

Canine teeth usually have pointed, conical crowns that often are longer than the incisors. Dogs, cats, and some other carnivores have extremely long canine teeth, called fangs, which are used to tear food. Humans have four canines—two in the upper dental arch and two in the lower—adjacent to the incisors.

Premolars or bicuspids have crowns with two prominent cusps or eminences. Humans have eight premolars, four in each dental arch; two lie behind each canine tooth. Twelve molars are situated at the back of the dental arches, six in the upper and six in the lower. The molars have four cusps, except the last, which have only three. The function of premolars is grinding and chewing. Thus, in herbivorous animals, which eat coarse plant material, these teeth are very flat—whereas in carnivores, which eat meat, they are sharply pointed.

THE STRUCTURE OF BONY TEETH

Internally a bony tooth is composed of several parts. At the center is the pulp cavity, which contains the soft, reddish pulp made up of connective tissue. This tissue is supplied with blood vessels and nerves that enter through the base of

4

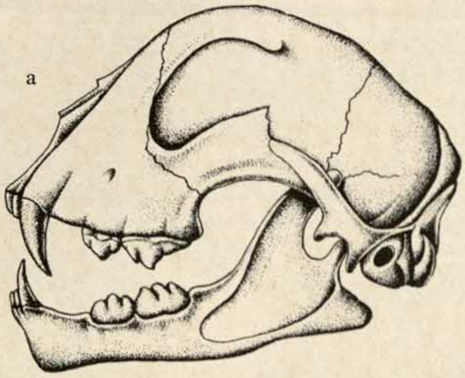
THREE TYPES OF DENTITION—Among mammals, four types of teeth are common: incisors, canines, premolars, and molars. The numbers and shapes of these teeth vary with the feeding habits of the animals.

Carnivorous animals like the cheetah (Illustration 4a) and the fox (Illustration 4a′) are meat eaters; their teeth are suited to cutting and tearing meat. The long, pointed incisors are used in grasping prey and cutting meat; the sharp premolars and molars shear meat. In some carnivores the molars are not well developed. The powerful jaws permit many carnivores to kill large prey and to crunch bones.

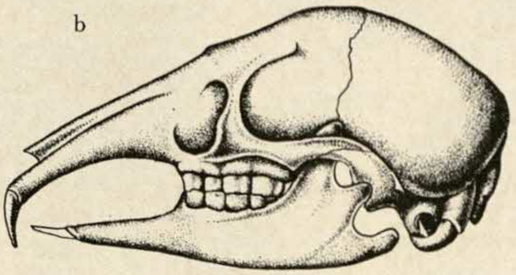
Rodents like the marmot (Illustration 4b′) feed on nuts and seeds and other materials that require much gnawing to remove a hard outer coat. Some rodents, like beavers, may gnaw wood to obtain building materials for their homes. The incisors of rodents (Illustration 4b), unlike those of carnivores, are long and sharp. The action of the upper incisors against the lower ones keeps them filed to a sharp edge. These teeth never wear down because any wear on the crown is compensated by the continuous growth from the base. Rodents lack canines, but they have flat molars.

Herbivorous animals like the horse (Illustration 4c) and sheep (Illustration 4c′), which eat grass and other relatively tender plant material, have large incisors used in cropping grass. Some have incisors only in the lower jaw, the upper jaw having a horny ridge. Others, like the horse, have upper incisors. Flat molars that grind vegetation are typical of herbivores. The upper molars of the horse have unusually high crowns.

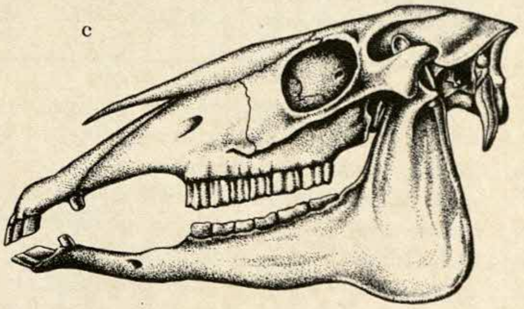
a



b



c



a′

b′

c′

the tooth. A toothache is the result of the stimulation of these nerves.

The pulp is surrounded by a more solid protective part, the dentin, or ivory—an extremely hard, yellowish-ivory substance similar to bone. The ivory is crossed by a great number of tiny dentin tubules, which run from the pulp cavity in a slightly undulating course toward the outer surface of the dentin. Surrounding the tubules is a hard matrix of collagenous fibers and calcified ground substance. In the outer part of the pulp is a layer of odontoblast cells that produce the dentin. Odontoblasts have fine fibers, called Tomes's fibers, that extend into the dentin tubules. These fibers are responsible for the formation of new tubules. In spite of the fact that it is not supplied with nerve fibers, dentin is sensitive to touch, cold, and acid solutions. Tomes's fibers are believed to transmit sensation to the nerve fibers of the pulp.

Dentin is covered with enamel on the crown and with cementum on the roots. Enamel is even harder than dentin; it contains only [illegible] percent organic material, but consists of long hexagonal prisms of calcium phosphate about 5-6 μm in diameter, cemented to each other by more calcium phosphate and arranged perpendicularly to the surface of the tooth. When a tooth is formed, the enamel is produced by cells called ameloblasts in a special structure, the enamel organ. When the enamel is completed, the ameloblasts die and no additional enamel is formed (enamel that is worn away cannot be replaced). Enamel receives its nourishment from the dentin it covers. There is some fluid circulation but no nerve supply in enamel.

DENTITION OF MAMMALS

The dentition of an animal reflects its habits and the nature of its alimentation. A dog, which has the typical dentition of a carnivore, has 42 teeth: each dental arch has six rather small incisors with limited functions, two sharp and highly developed canines, eight cutting premolars that increase in size from front to back, and four flat molars that have rounded tubercules on their surface. On the mandible (the lower jaw) there are two more molars (which are used in gnawing bones), one left and one right.

DECIDUOUS TEETH

In a normal lifetime, humans and many other mammals possess two sets of teeth. The first set, which consist of deciduous or milk teeth, has only twenty teeth: eight incisors, four canines, and eight premolars, half of which are in the upper dental arch and half in the lower. The first deciduous teeth to erupt from the gum usually appear at about six months of age and the last at about two years.

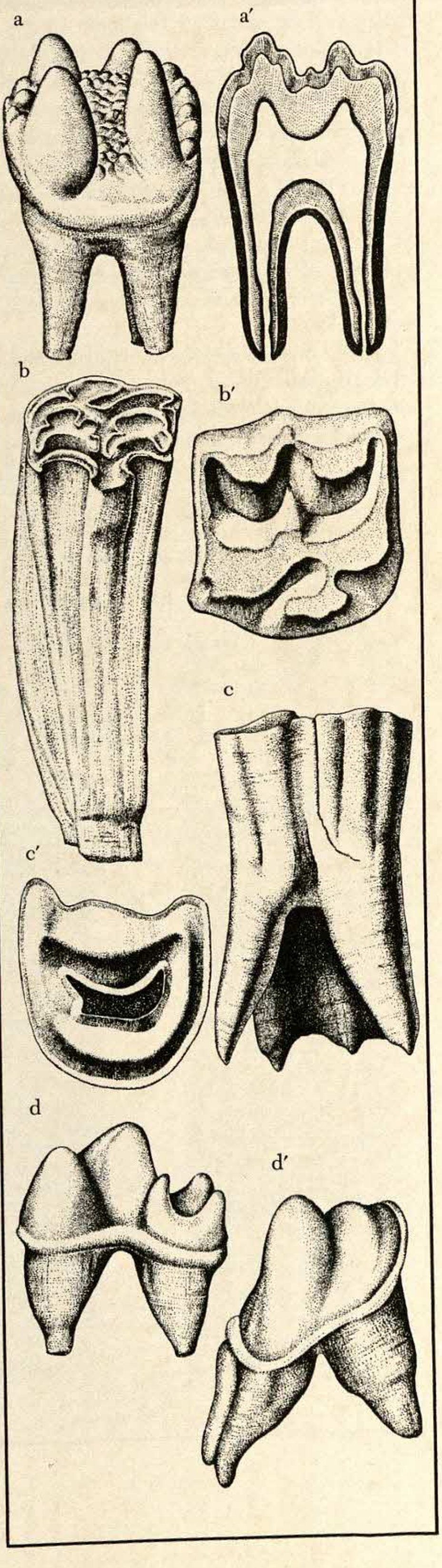
The first deciduous teeth fall out and are replaced by permanent teeth, which begin to erupt about the sixth year. The last to appear are the backmost molars, sometimes called wisdom teeth because they often erupt around the twenty-first year. In many persons, however, the wisdom teeth remain within the jawbone.

The rabbit has no canine teeth, and there is an empty space called a diastem between the incisors and the molars, both upper and lower. The four huge, arched incisors, two above and two below, sink like scalpels deep into food, working in a matched and continuous motion. The movement of the upper incisors against the lower ones causes the teeth to wear down and develop a chisellike form. Because they have no roots, these teeth grow continuously as the surfaces of the crowns wear down. Behind the incisors, the rabbit has two other incisors that are hardly visible. The 24 molars have rough, flat crowns and exert a filing action. They also are replaced continuously, but at a slower rate than the incisors. The rabbit, —along with such rodents as the squirrel, hare, and mouse—has a total of 28 teeth.

In the herbivores, such as the cow, the incisors and canines are completely within the upper jaw, where they are replaced by a kind of horny ridge. There are six spatula-shaped incisors on the lower jaw, as well as two small canines that are similar to the incisors in their flattened form. The upper jaw, like the lower, has 12 large molars that are continuously replaced. Both above and below is a toothless space between the canines and the molars—called the bit—that is analogous to the diastem in the rabbit. The cow's incisors seize the forage and cut it into mouthfuls. The true grinding machine, however—an arrangement capable of grinding down straw and hay —is made up of 24 strong molars.

5

DIFFERENT ASPECTS OF MOLARS—These drawings show the differences among four types of molars belonging to different animals: upper molar of a pig (5a); a longitudinal section of the same (5a′); upper molar of a horse, with its high crown and grinding surface (5b); the grinding surface (5b′); upper molar of an ox (5c); its chewing surface (5c′); the tooth of a dog, from the tongue side (5d) and from the lip side (5d′).



THE STRUCTURE OF THE NERVOUS SYSTEM

types of neurons and their organization

The neurons, or nerve cells, that make up the nervous system are organized in an exceedingly complex manner, but they can be classified relatively simply. The entire nervous system is divided into two main parts: the central nervous system and the peripheral nervous system. The function of the central nervous system, which consists of the brain and the spinal cord, is the efficient sorting out and organization of impulses brought to it by the peripheral nervous system. The latter consists of nerves that extend from the brain or spinal cord to the other parts of the body.

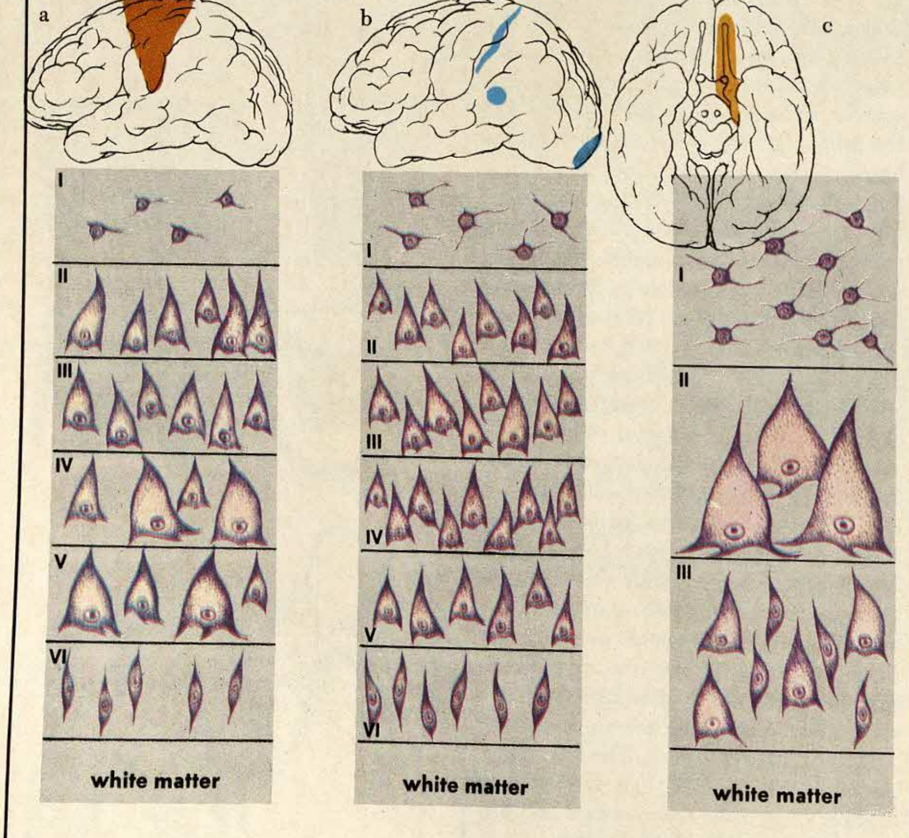
Each nerve contains many neurons. The spinal nerves and some cranial nerves are mixed nerves, containing both sensory and motor neurons. Other cranial nerves have neurons of only one type.

The peripheral nervous system is divided into two parts: the somatic nervous system and the autonomic nervous system. The neurons of the somatic nervous system serve the skeletal muscles, the joints, and the skin; they are involved with voluntary control of these organs. The neurons of the autonomic nervous system serve the smooth muscles of the viscera (stomach, intestines, and so forth), the cardiac muscle, and the glands; these neurons are involved in the automatic, involuntary control of these organs. A single peripheral nerve may contain neurons of both the somatic and autonomic nervous system.

As a spinal nerve approaches the spinal cord, it divides into two branches: the

1

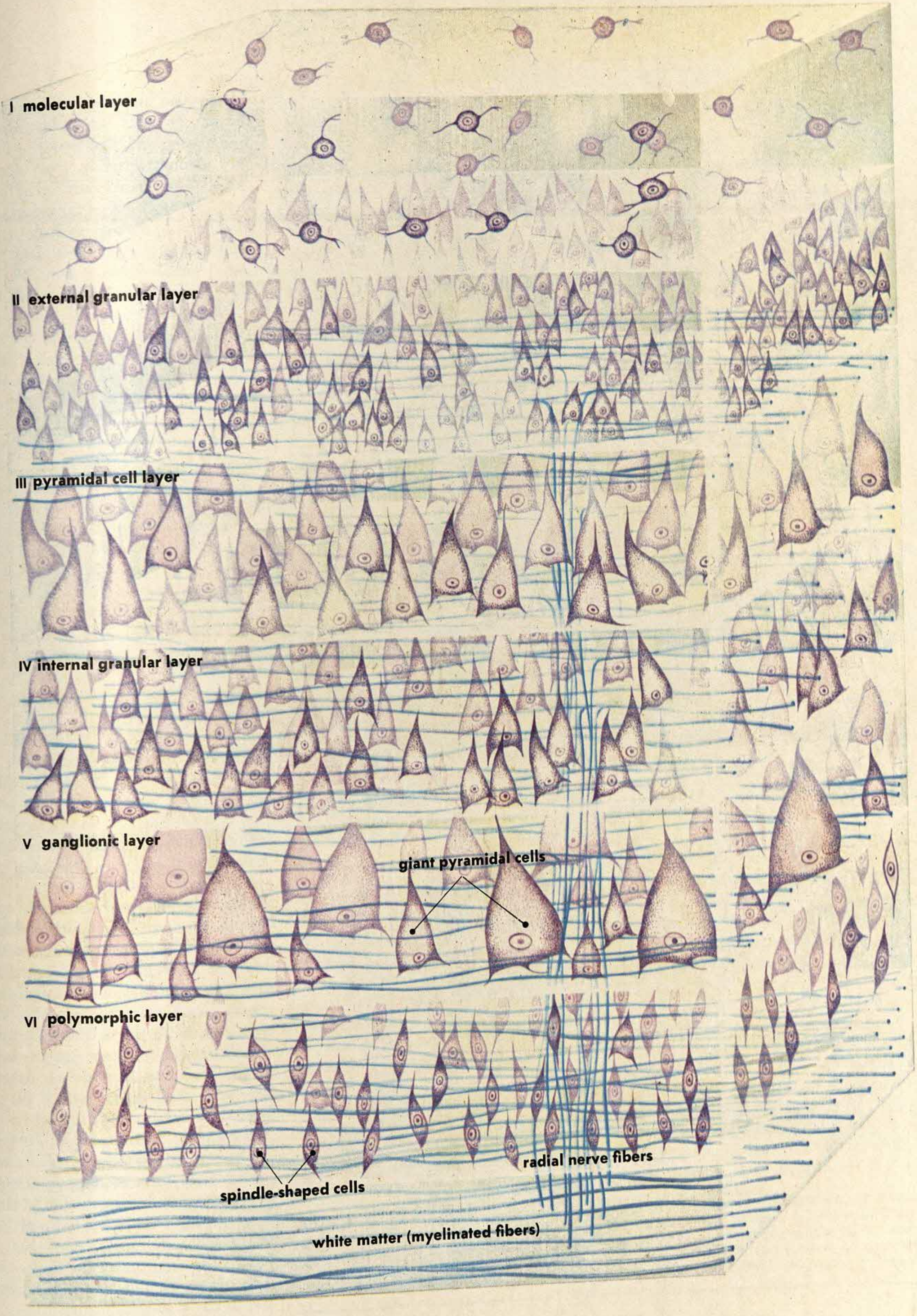
THE CEREBRAL CORTEX—The cerebral cortex is divided into the isocortex and the allocortex. The isocortex has six layers of cells. Three types of cortex are shown: Illustration 1a shows nongranular cortex, present in the precentral motor area; Illustration 1b shows exclusively granular cortex, present in various zones; and Illustration 1c shows a kind of allocortex with only three layers.



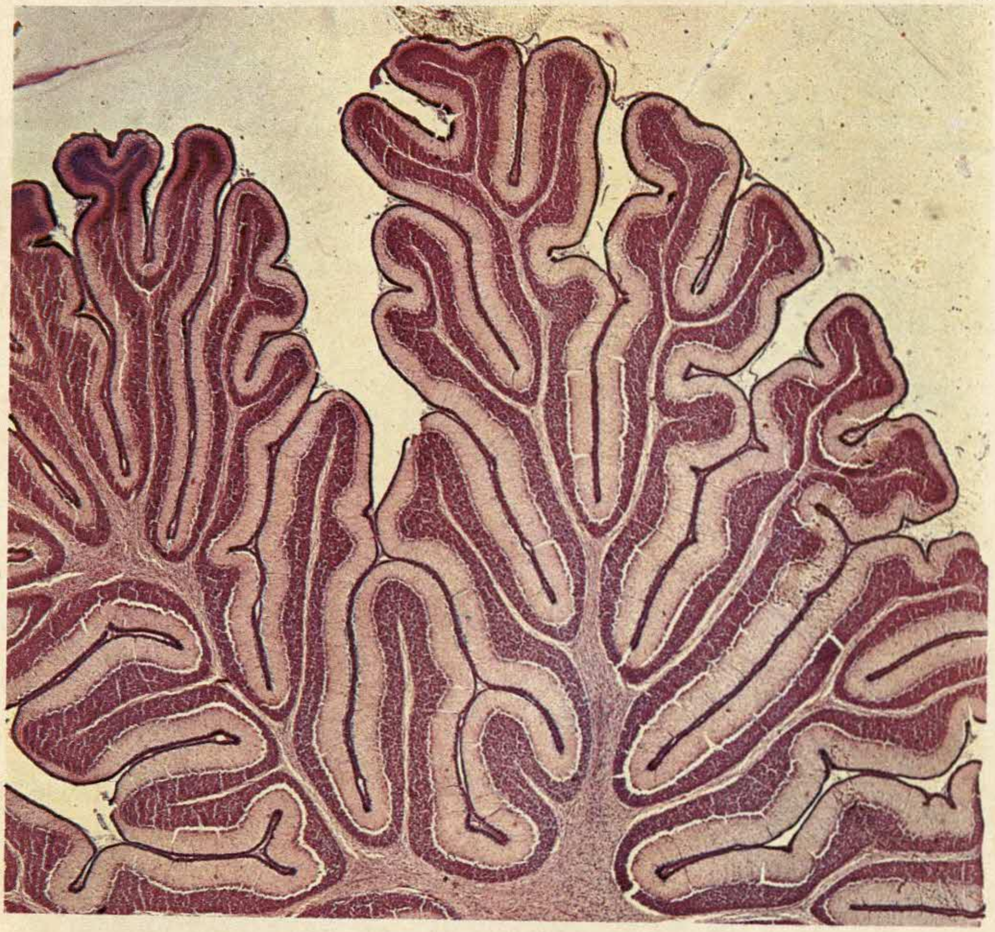
MICROSCOPIC STRUCTURE OF THE CEREBRAL CORTEX—Illustration 2a is a microscopic section of a portion of the cerebral cortex of an ox. (200 X) Because the ox is a mammal high on the evolutionary scale, its cortex is quite similar to that of man. Illustration 2b is a three-dimensional diagram of the characteristic stratification of the cells and the fibers of the isocortex.

2a

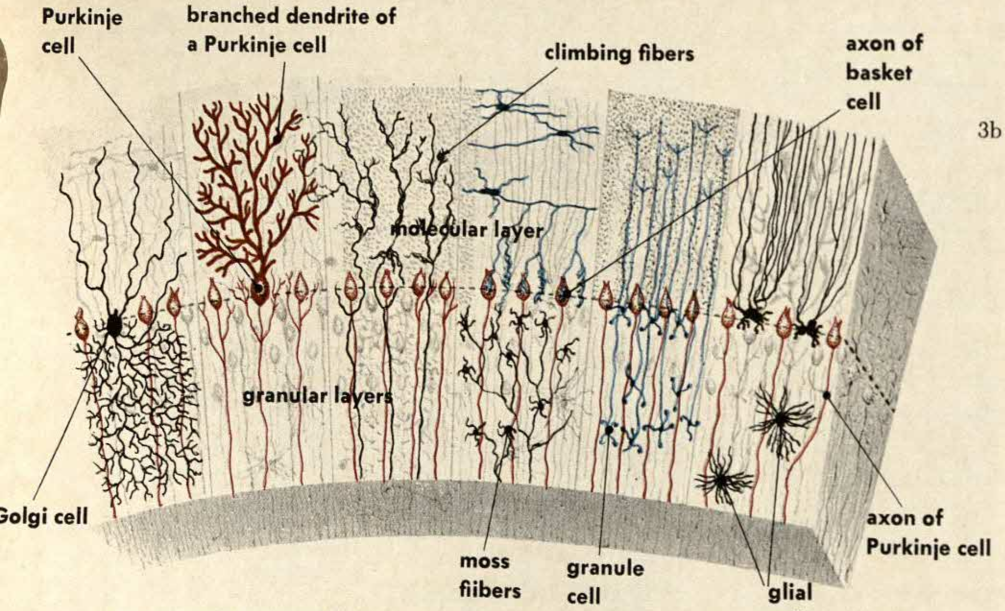
2b


I molecular layer
II external granular layer
III pyramidal cell layer
IV internal granular layer
V ganglionic layer
giant pyramidal cells
VI polymorphic layer
radial nerve fibers
spindle-shaped cells
white matter (myelinated fibers)

3a



3b



CEREBELLAR CORTEX—The cerebellar cortex (Illustration 3a) is folded into ridges called folia. White matter (light pink in this stained microscope section) extend into the folia. Two layers of gray matter (dark pink and an outer light pink layer) surround the white matter. Illustration 3b is an enlarged diagram of gray matter. The outer layer is the molecular layer; the inner is the granular layer.

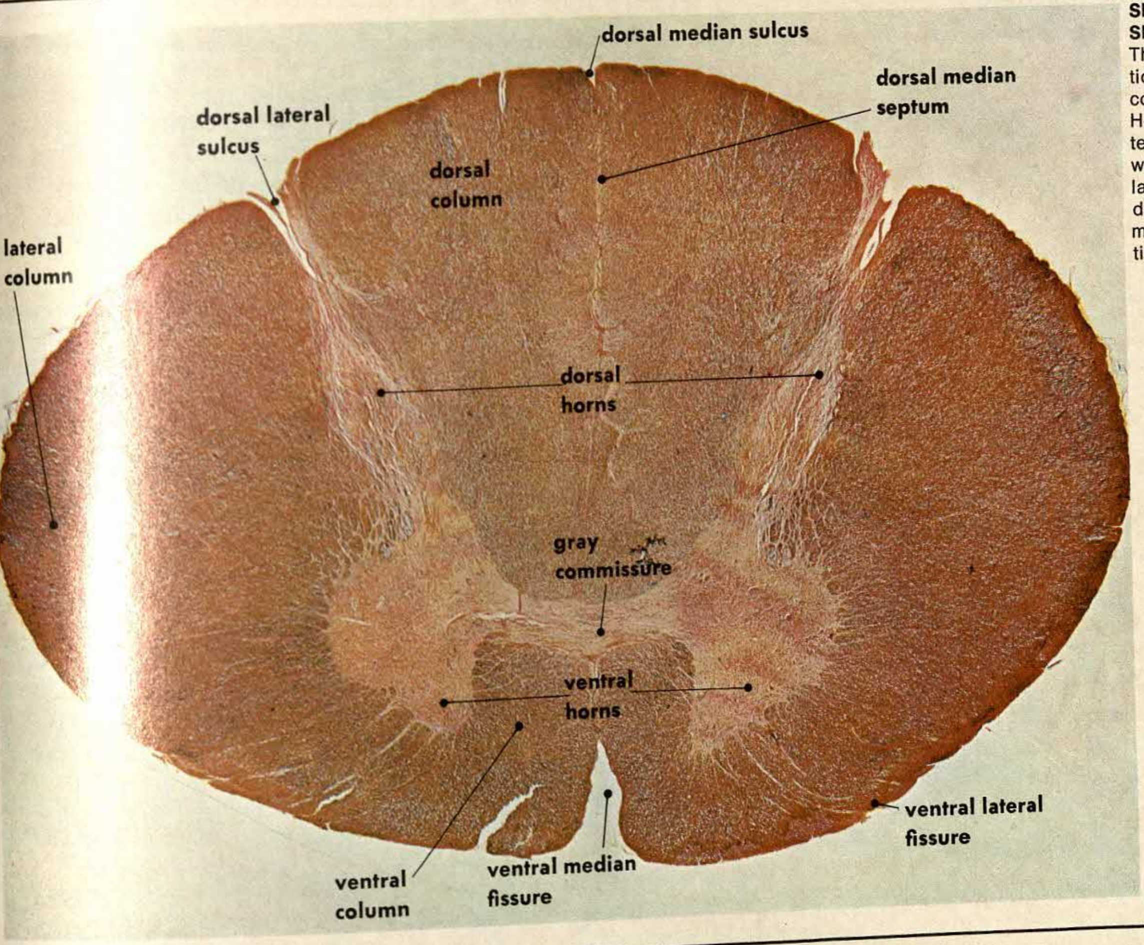
dorsal root and the ventral root. The dorsal root has an enlargement, the spinal ganglion. The dendrite of a sensory neuron extends from the organ served to the spinal ganglion in the dorsal root. The cell body of the sensory neuron lies in the ganglion, and the axon continues through the dorsal root into the spinal cord, where it synapses with a connector neuron. Connector neurons are confined to the central nervous system. The short dendrite and the cell body of a motor neuron lie within the spinal cord; its axon leaves by way of the ventral root, then extends the length of the spinal nerve to the organ served.

Cutting the dorsal root of a nerve anesthetizes the area served by the nerve; the brain receives no sensations if this area is stimulated. Any muscles or glands served by the nerve can still function. If the ventral root is cut instead, the muscles served by it become paralyzed, but appropriate sensations are perceived by the brain when the area is stimulated. If both the dorsal and ventral roots of a nerve are cut, or if the nerve is severed beyond these roots, the area it serves is both paralyzed and deadened to all stimulation.

A cross section of the spinal cord reveals that white matter surrounds an H-shaped column at its center, which is composed of gray matter. Two horns of the H point dorsally, and two point ventrally. The cross bar of the H is the gray commissure; in it lies the small central canal of the spinal cord.

The cell bodies of connector neurons receiving sensory impulses lie in the dorsal horns, while the cell bodies of motor neurons are located in the ventral horns. The white matter consists largely of the processes of connector neurons that ascend to the brain or descend from it. The neurons tend to run in bundles called tracts. Many of the ascending tracts lie in the dorsal part of the spinal cord, but some occupy lateral and ventral areas as well. Descending tracts lie in the lateral and ventral parts of the spinal cord. Most of the ascending and descending fibers run a fairly straight vertical course on either the right or the left side of the spinal cord, but some cross over from one side to the other. This occurs in the white matter just ventral to the gray commissure.

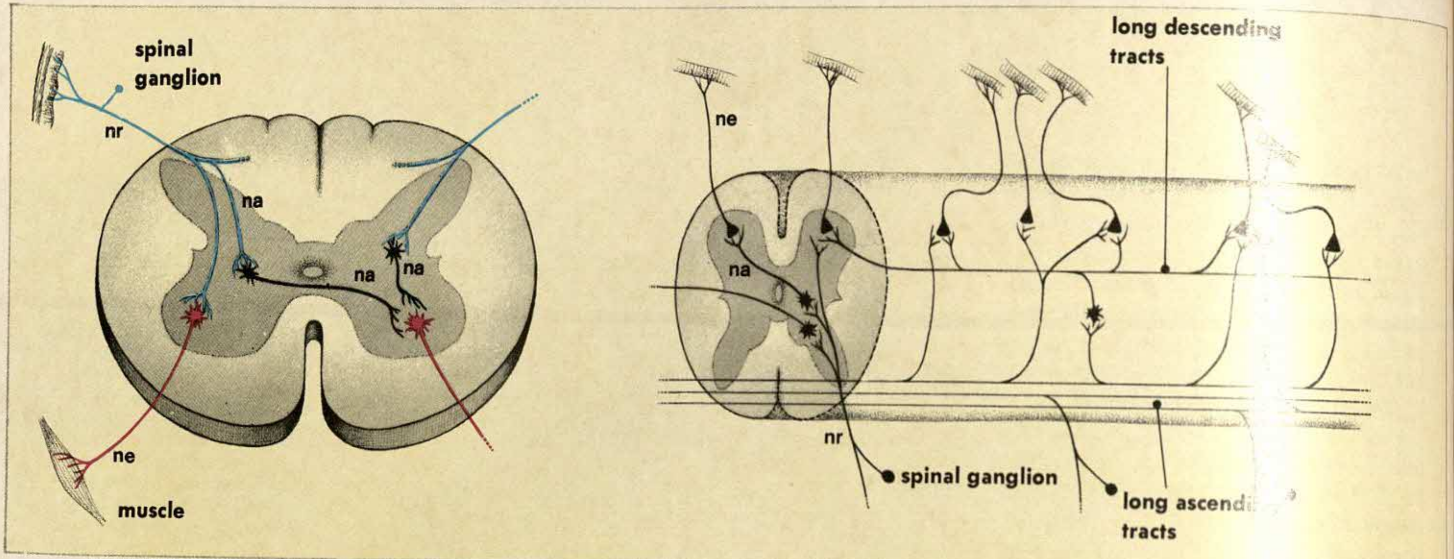
4



SECTION OF THE SPINAL CORD— This transverse section of the spinal cord shows the H-shaped gray matter surrounded by white matter. The latter is stained darker than the gray matter in this section.

The autonomic nervous system, which controls involuntary actions, is divided into two parts: the sympathetic nervous system and the parasympathetic nervous system. Nearly all internal organs are served by both parts, and they have opposite effects. The sympathetic nervous system strengthens and accelerates heartbeat, raises blood pressure, decreases activity of the digestive tract, dilates the pupil of the eye, relaxes the urinary bladder, and facilitates breathing by dilating the bronchi of the respiratory system. The parasympathetic nervous system, on the other hand, weakens and slows heartbeat, lowers blood pressure, increases activity of the digestive tract, constricts the pupil, constricts the urinary bladder, and constricts the bronchi. The neurons of the peripheral part of the sympathetic nervous system are associated with the spinal nerves of the thoracic and lumbar regions. Those of the parasympathetic nervous system are part of several cranial nerves and the spinal nerves of the sacral region.

The autonomic nervous system is an important part of the mechanism with which the body maintains homeostasis—such constants of internal environment as fluid balance and temperature. The sympathetic system is a vital part of the mechanism by which a person reacts to stress. A situation that causes fear or rage, for example, may also result in the increase of blood pressure, pulse rate, cardiac output, and blood sugar. These "fight or flight" responses to stress are widespread because the sympathetic nervous system has many connections and because adrenaline, formed by the medullary cells of the adrenal glands, is released into the bloodstream. More slowly developing changes may also follow stress. These alterations, brought about by activation of the hypothalamic-pituitary system, lead to changes in the function of the endocrine organs.

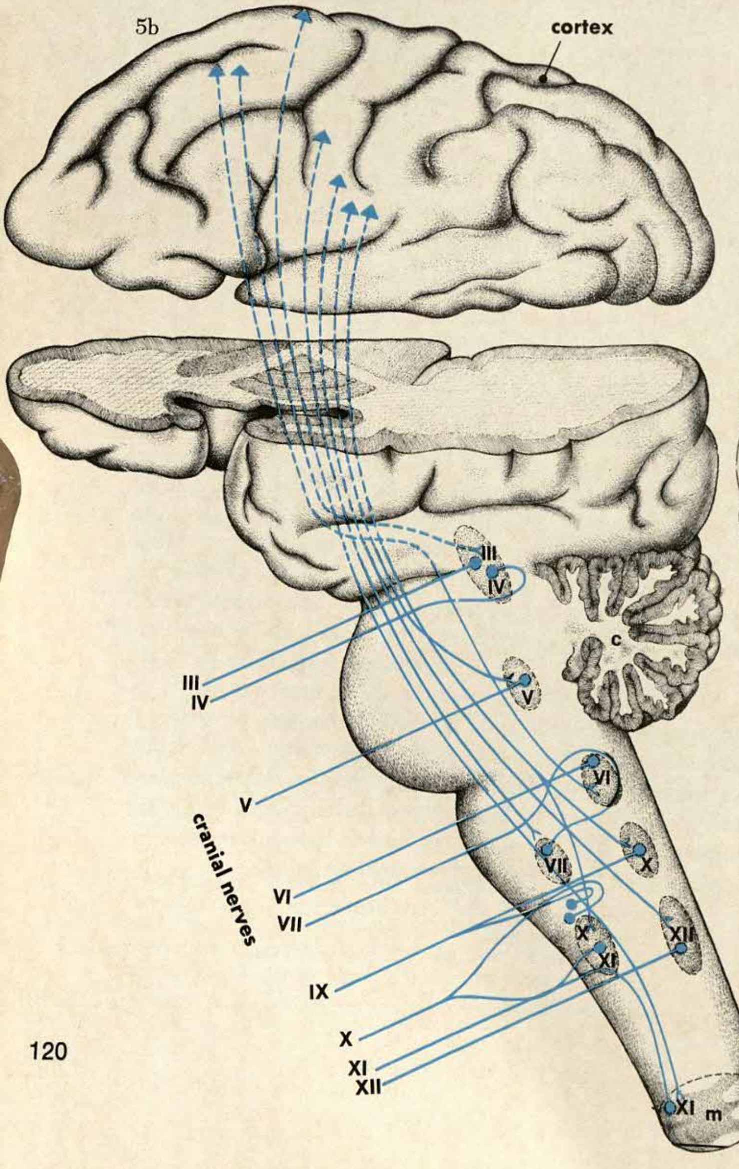


EXAMPLES OF NERVE TRACTS—Illustrations 5a and 5a′ illustrate schematically the connection between the various neurons in the spinal cord. A reflex arc transfers a stimulus from a sensory organ to a muscle or gland. The simplest arc is formed of two neurons, that is, a sensory (afferent) neuron **nr** and a motor (efferent) neuron **ne.** More often, the sensory neuron communicates with one or more connector, or association, neurons **na,** which communicate with motor neurons or with other connector neurons. Illustration 5a′ shows the path of neurons in a tract of the spinal column.

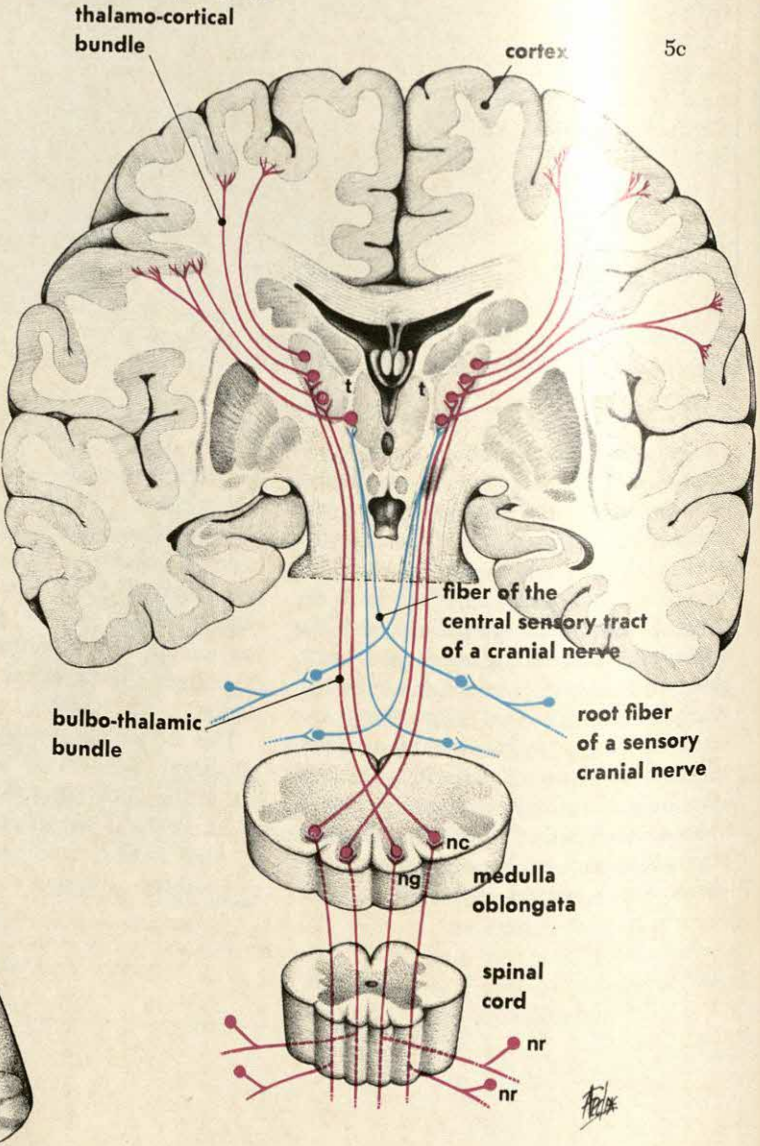
Illustration 5b is a schematic representation of the direct motor tract, also called the pyramidal tract, which descends from the cortex to the spinal cord. The nerve bundle passes from the cortex to the mesencephalon and to the pons, where it forms pyramid-shaped bulges on the surface. Here some neurons pass from the right side to the left or from left to right.

Illustration 5c shows one example of the central sensory tract. The stimulus is received by sensory neurons **nr** and ascends the spinal column to the nucleus gracilis **ng** and the nucleus cuneatus **nc** in the medulla oblongata. From this point, another bundle of fibers ascends to the thalamus **t.** Here they synapse with neurons that reach the cerebral cortex. A sensory tract of this type is called bulbo-thalamic; it transmits sensations received by the peripheral receptors.

5b



5c


thalamo-cortical bundle
cortex
t
t
fiber of the central sensory tract of a cranial nerve
bulbo-thalamic bundle
root fiber of a sensory cranial nerve
nc
ng
medulla oblongata
spinal cord
nr
nr

NERVE TISSUE | the control tower of human functions

All vital activities of the human body are governed by one complex mechanism of regulation and control: the nervous system. Comparable to a vast, extraordinarily complex telephone network, it takes in information from all parts of the body concerning the condition of the body's various components as well as conditions in the outside world. This data is transmitted through the peripheral nerves to the central nervous system; there the communications are rapidly analyzed and coordinated, whereupon orders are sent to the various organs of the body. This enables the latter to adapt to external conditions; and thus, the life of the organism continues efficiently and harmoniously.

The nervous system is made up of tissue that is specifically differentiated to receive stimuli and transmit impulses. These functions are rendered possible by the particular structure of the neurons. (A neuron is a single nerve cell, and is the smallest morphological unit of the nervous system.) The brain, spinal cord, and nerves consist largely of neurons. The neurons in nerves lie parallel to each other.

NERVE CELL—A nerve cell or neuron consists of a cell body, in which the nucleus is located, and of one or more processes that extend from the cell body. Some neurons are more than a meter (about 3 ft) long. The processes may extend several feet. (1,360 X)

STRUCTURE OF THE NEURON

Although neurons have a great variety of forms, they also have some common characteristics. Each has a cell body with a nucleus in the cytoplasm. Long, slender cytoplasmic processes—varying a great deal in length—extend from the cell body. Some extend from the spinal cord to the feet, to a length of almost 1 m (about 3 ft). Two types of processes exist: dendrites and axons. Dendrites transmit an impulse toward the cell body, and axons transmit it away from the cell body.

The nucleus of a neuron is large and spherical; it has a vesicular aspect and stains lightly. Usually the nucleus contains one small dark nucleolus. The cytoplasm contains abundant mitochondria, and the Golgi apparatus is very extensive. Unique to the cytoplasm of neurons is a network of neurofibrils that, in turn, are composed of extremely fine proteinaceous filaments called neurofilaments, 0.006 to 0.008 μm in diameter. They occupy not only the cytoplasm of the cell body but that of the processes as well. Also characteristic of neurons are the Nissl bodies, organelles composed of endoplasmic reticulum and ribosomes; the latter are the site of the protein synthesis in the cell. Nissl bodies are found in the cytoplasm of cell bodies and dendrites, but never in axons.

Nerve cells in adult tissues are incapable of cell division. When one dies, it cannot be replaced.

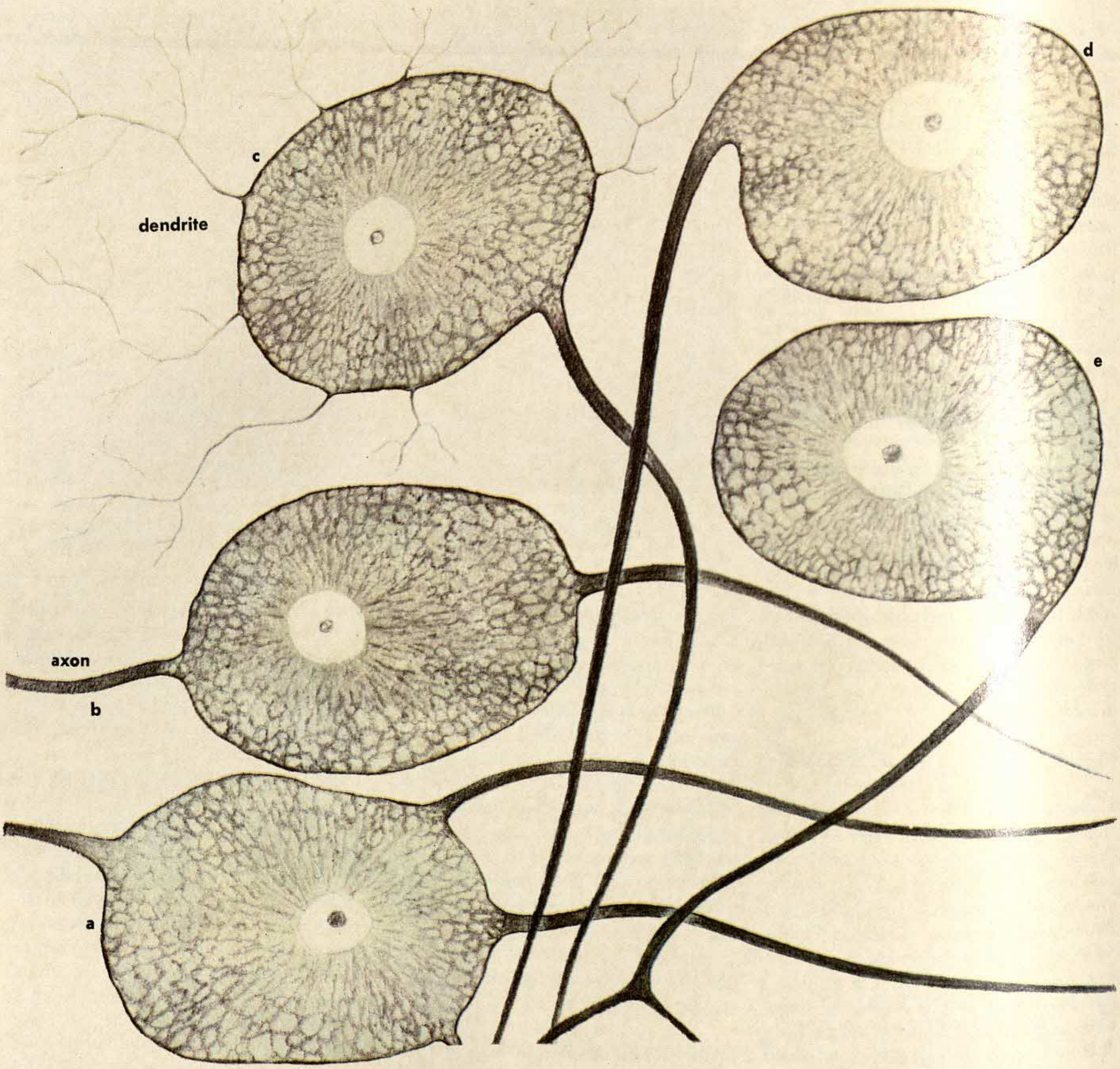
DENDRITES AND AXONS

Some neurons have only one dendrite, but many neurons have several. Usually there is only one axon in a cell. Both dendrites and axons may branch more or less profusely. The endings of an axon meet the dendrites of other nerves, or they terminate on muscle or gland cells. In the former case, an impulse is transmitted from the axon to the dendrite of the next cell in the neural pathway. In the latter case, an impulse from the axon stimulates a muscle or a gland.

CLASSIFICATION OF NEURONS

The three types of neurons are sensory, connector, and motor neurons. The dendrites of sensory neurons receive stimuli from either the external or internal environment. The stimulation initiates an impulse that travels from the dendrite to the cell body and then to the axon. The impulse then travels to the dendrite of a connector neuron, then to its cell body and axon. A motor neuron then receives an impulse from a connector neuron. The axon of a motor neuron terminates on a muscle cell, which it stimulates to contract.

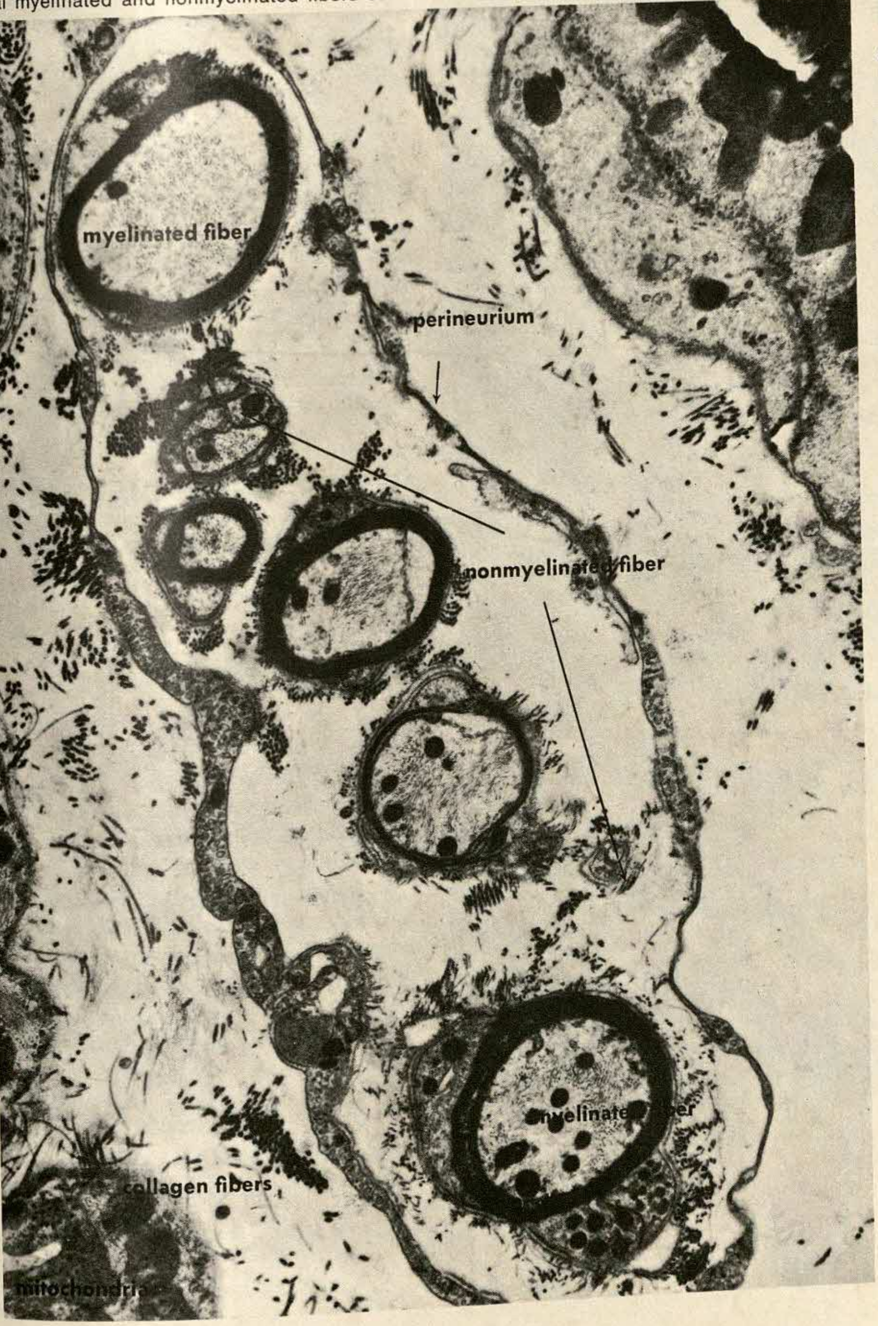
Neurons also may be classified on the basis of the number and type of their processes. Unipolar neurons are cells

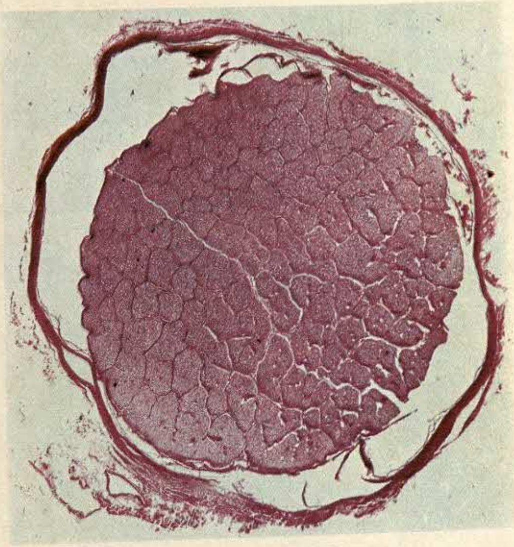


VARIOUS TYPES OF NEURONS—Illustration 2 shows a neuron with numerous axons **a;** a bipolar neuron with one axon and one dendrite at opposite poles of the cell **b;** a multipolar neuron with one axon and several dendrites **c;** a unipolar neuron with a single process, the axon **d** (rare in adult tissues); and a pseudounipolar neuron with a single T-shaped process formed by fusion of dendrite and axon **e.**

with an axon and no dendrite. Although uncommon in adult tissues, they are found in embryonic tissues. Bipolar neurons having one axon and one dendrite at opposite ends of the cell body are found in the olfactory epithelium of the nose and the retina of the eye. Pseudounipolar neurons have a single axon and a single dendrite that are separate when the cell is formed but later fuse near the cell body, giving the appearance of a single T-shaped process. Multipolar neurons have one axon and several dendrites. They are the most common type of neuron, and they vary in shape. Many are star-shaped or pyramidal. Neurons with a single dendrite are found in man only in the retina.

ELECTRON MICROGRAPH OF PERINEURIUM —The illustration shows cross sections of several myelinated and nonmyelinated fibers surrounded by perineurium, a connective tissue that binds the nerve fibers together. (14,800 X)





CROSS SECTION OF THE OPTIC NERVE— Epineurium, a relatively thick layer of connective tissue, surrounds the entire nerve. The individual nerve fibers are not visible at this low magnification, but the bundles into which they are grouped can be seen.

THE NEURILEMMA, MYELIN SHEATH, AND NEUROGLIA

Nerve fibers typically are covered by one or two sheaths. The neurilemma is formed by unusual cells called Schwann's cells. A single Schwann's cell envelops a length of one or a few nerve fibers. The neurilemma is gray; it surrounds the fibers of peripheral nerves and contributes to their color. The neurilemma is essential for the regeneration of injured neurons. If a fiber is cut, the part without a cell body dies; the other part may slowly grow forward, replacing the lost part. Not all cells with a neurilemma regenerate successfully, but those lacking it do not regenerate at all.

CONNECTIVE TISSUES AND NERVES

Each nerve is surrounded by a layer of strong connective tissue called epineurium. Within the nerve, the neurons are grouped into several fascicles, each fascicle being surrounded by connective tissue called perineurium. Endoneurium is fine, delicate connective tissue that

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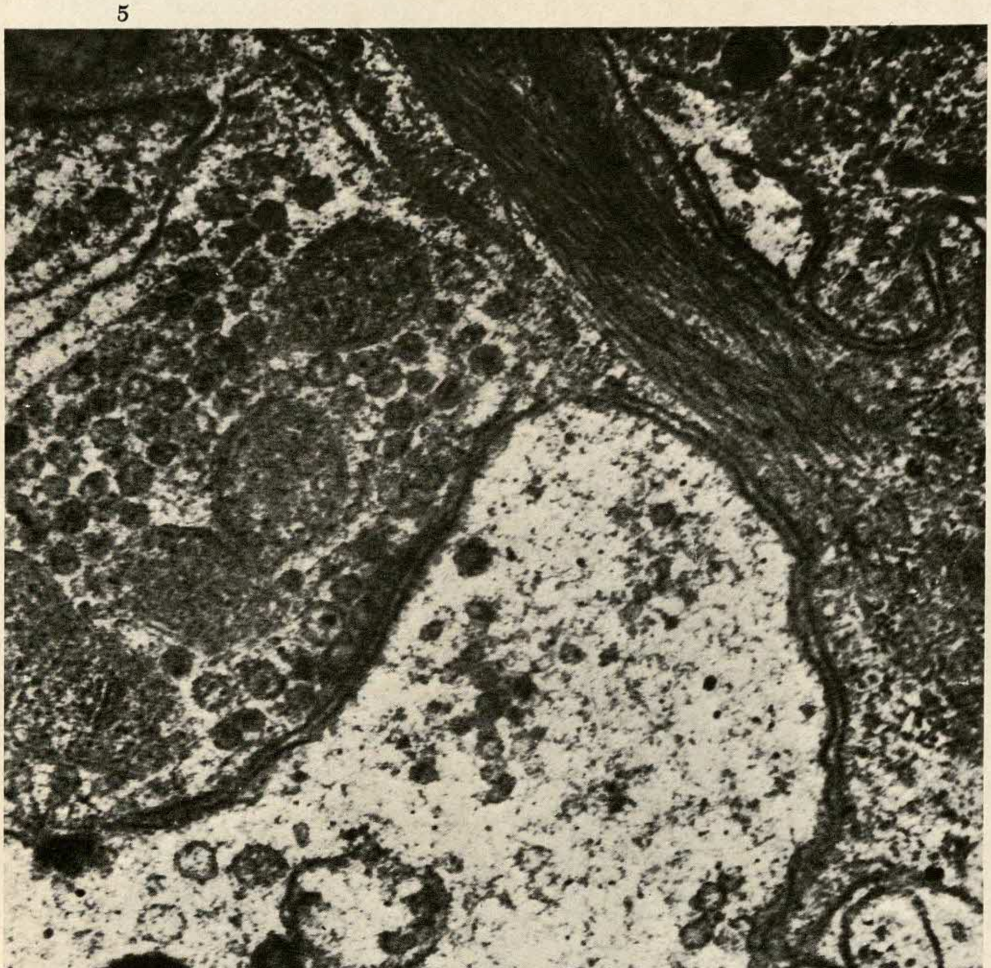

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A NERVE ENDING—One end of a rod cell of the retina of the eye (Illustration 5) extends into a pigment cell. (70,000 X)

NERVE GANGLION—A ganglion (Illustration 6) is a swelling on a nerve. Within the ganglion are the cell bodies of the neurons. The nucleus of a neuron is spherical and has a single dark nucleolus. (400 X)

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envelops individual neurons, it is known also as the sheath of Henle. Small blood vessels in these connective tissues supply the nerve cells with food and oxygen.

SYNAPSES AND NEUROMOTOR JUNCTIONS

When an impulse travels from one neuron to another, it crosses a small gap, for the neurons do not actually touch each other. The gap, which is called a synapse, may be 0.006 to 0.02 μm wide. Schwann's cells and glial cells do not cover the ends of dendrites or axons in synapses.

A similar gap exists between the ending of a motor axon and the muscle it serves. Such a gap is spoken of as a neuromotor junction. The axon endings here often are flattened where they meet the muscle cell. These endings are called motor end plates.

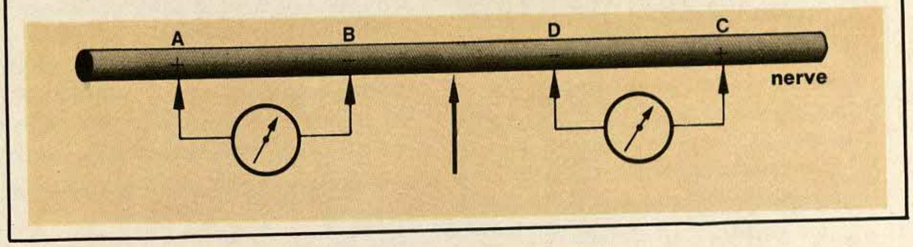
THE NATURE OF THE NERVE IMPULSE

stimulation and excitation

A coded message is difficult enough to decipher—but an invisible, soundless one is even more difficult to understand. Such a message is the nerve impulse that travels at rapid speed along the nerves.

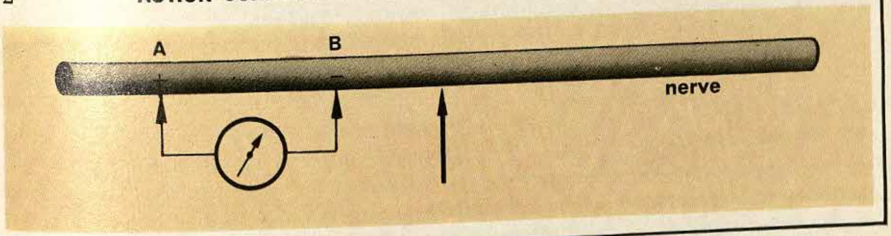
Once it was thought that nerve impulses were simply electric currents, but electricity travels much faster than any known nerve impulse. The sciatic nerve of a frog has an impulse transmission velocity of about 30 m (about 100 ft) per second; the motor nerves of mammals have somewhat higher speeds. Some neurons with myelin sheaths transmit impulses at 120 m (about 400 ft) per second. Nonmyelinated fibers transmit more slowly. By contrast, an electric current travels at the rate of 300,000 km (about 186,000 mi) per second. Obviously, a nerve impulse must involve more than a pure electric current.

1 **CONDITION OF NEGATIVE ELECTRICITY**



Another early misconception was that the impulse was carried by the numerous neurofibrils that occupy the cytoplasm of a neuron. These fibrils are oriented with their long axes in the general direction of the path followed by the impulse. The present conception of the transmission of the nerve impulse pictures it as an electrochemical phenomenon involving the passage of electrically charged chemical particles (ions) across the membrane of the neuron.

2 **ACTION CURRENT OF THE NERVE**



THE RESTING NEURON

A neuron that is not transmitting an impulse is a resting neuron. Its membrane is relatively impermeable to sodium ions, which are present outside the cell in concentrations about ten times greater than their concentration within the cell. The resting neuron continually expends energy, preventing the sodium ions from diffusing into the cell; thus the cell maintains the concentration differential. Sodium ions are positively charged, and their concentration differential sets up a difference in electric charge between the two surfaces of the cell membrane.

Sodium is not the only ion having different concentrations inside and outside a resting neuron. Chloride ions, which have a negative charge, are more concentrated outside the cell than inside. Potassium ions, which have positive charges, and organic ions are more concentrated inside than outside the cell. As a consequence of this unequal distribution of ions, the difference in electrical charges—which is called the resting membrane potential—measures about 0.07 V (volts). The outside of the cell membrane was found to have the more positive charge.

THE NERVE IMPULSE

When a portion of a neuron, usually the end of a dendrite, is stimulated, a sudden increase in the permeability of the membrane to sodium ions occurs at the point of stimulation. As a result, sodium ions in this area move quickly across the membrane into the cell. Their positive charges make the inside of the cell more positive than the outside by about 0.05 V. This difference is called the active membrane potential, and that small area of the cell is said to be depolarized.

Because an active membrane potential exists adjacent to a resting membrane potential, a circular current, called an action current, is set up. In the region of the active membrane potential the current flows from the outer, negatively charged area to the inner, positively charged area. It then moves along the inner side of the membrane to the region of the resting membrane potential, where the charge on the inside of the membrane is negative. From here it crosses the membrane to the outer side where the charge is positive. Finally it moves back to the outer, negatively charged area in the region of the active membrane potential. Thus, it follows a complete circuit that passes twice across the membrane.

At this point two things happen. In the area of active membrane potential, the sodium ions are pumped out of the cell, and the resting membrane potential returns. The area is now repolarized. In the new area through which the circular

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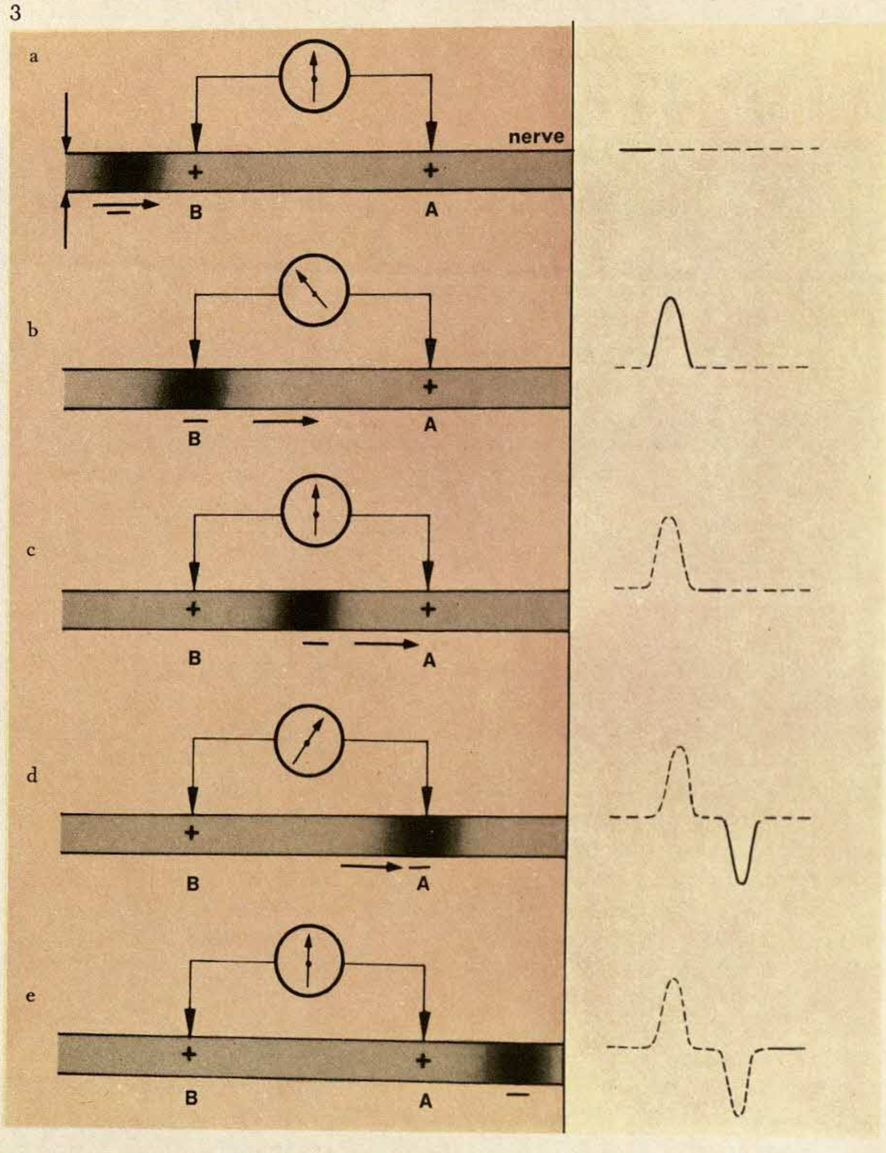

THE PASSAGE OF A NERVE IMPULSE—As an impulse travels along a neuron, changes in electric potential occur. These are measured by two electrodes connected to a nerve and then to a galvanometer. A brief stimulus is applied; the galvanometer shows no potential difference before the impulse reaches electrode **B** (Illustration 3a). When the impulse reaches electrode **B,** it becomes temporarily negative with respect to electrode **A** (Illustration 3b). With the impulse between them, both electrodes register the same potential (Illustration 3c). After a short time **A** becomes negative with respect to **B** as the impulse reaches it (Illustration 3d). When the impulse passes, **A** and **B** have the same potential again (Illustration 3e). A given neuron can transmit several hundred impulses per second.

action current flowed, an active membrane potential is set up. As a result, the action current is shifted a short distance along the length of the neuron, and the entire process is repeated again and again.

The movement of the action current along the neuron is thus a self-propagating phenomenon. Wherever it is, it causes the movement of sodium ions into the cell in the area just ahead, and thus causes its own movement along the cell. The movement of the action current is the nerve impulse. A nerve impulse, in other words, is the movement of an electrochemical reaction along the neuron.

A nerve impulse has been compared with the movement of a spark along a fuse. The heat generated by the burning of one small segment of the fuse causes the next small segment to ignite, and so the spark propagates itself along the fuse. The impulse in any section of a neuron alters the next segment of the neuron in such a way that the impulse can move into it. There is a difference, however. A fuse can be used only once; it will not burn again. A neuron, on the other hand, restores itself to its original condition and can transmit impulse after impulse for its entire life.

After the transmission of an impulse, a short refractory period occurs during which the neuron cannot be stimulated. This is the time required for the membrane to become repolarized. The refractory period varies in length from 0.001 to 0.005 second, which means that a given neuron can transmit several hundred impulses per second.

Repolarization requires energy, for the sodium ions being pumped out of the cell must move against a concentration gradient to make their concentration higher outside the cell than inside. The energy used in this process probably comes from the ATP (adenosine triphosphate) produced in respiration, a universal energy-releasing chemical reaction in living cells. Respiration requires oxygen, and if neurons are deprived of oxygen, their ability to transmit impulses declines quickly.

Any portion of a neuron can be stimulated, and an impulse can flow in either direction from this point to the ends of the cell. In a living body, however, the direction of movement is nearly always in one direction: from dendrite to cell body to axon.

THE ALL-OR-NONE PRINCIPLE

All nerve impulses seem to be the same. The intensity of the stimulus has no effect on the strength of the impulse; the stimulus must merely be strong enough to initiate the impulse. This is called the all-or-none principle. Neither does the intensity of the stimulus have an effect on the speed of transmission of the impulse. The analogy with a fuse holds true here—the heat of the spark and the rate at which it moves down the fuse are independent of the size or temperature of the flame that ignited the fuse. The fuse might even have been ignited by light rays concentrated by a lens. The important thing is that enough heat be supplied to start the fuse burning. The rate at which the fuse burns depends on the nature of the fuse; the rate at which a nerve impulse travels depends on the nature of the neurons. Myelinated fibers transmit impulses faster than nonmyelinated fibers. Drugs also can influence the condition of the nerves and hence the rate of transmission.

A strong stimulus usually results in more impulses traveling along a neuron in rapid succession, and it may stimulate many neurons. This leads to the subjective impression that the impulse is stronger, when actually more impulses have been initiated.

SYNAPSES

The electrochemical phenomenon that is a nerve impulse does not travel across a synapse—the small gap that separates the axon of one neuron from the dendrite of another. Here the impulse becomes a chemical one, and the transmission is slower than it is along the cell membrane. At a synapse, transmission occurs in only one direction—from axon to dendrite. This explains why transmission along a neuron usually is in only one direction (even though it is possible for it to be in two directions). Ordinarily, only the dendrite of a neuron is stimulated—either by an external stimulus, such as light, sound, or touch, or by the transmission of an impulse across a synapse from another neuron.

The tip of an axon contains synaptic vesicles with diameters of 0.003 to 0.005 μm. These vesicles contain compounds called neurohumors that are released into the synapse only when a nerve impulse reaches the end of the axon. The compounds diffuse across the synapse and react with chemoreceptors on the surface of the dendrite. This stimulates the dendrite by increasing the permeability of its membrane to sodium ions and initiating a new action current. The impulse then travels along the second neuron as it does in the first; at the end of the axon of the second neuron, a synapse is bridged again by the production and release of more neurohumor.

At least two neurohumors are known. One called sympathin is released by neurons of the sympathetic nervous system (sympathin is identical with or similar to noradrenalin, a hormone already known to be secreted by endocrine glands). The other, acetylcholine, is released by neurons of the parasympathetic nervous system. Once released into synapses, these two neurohumors would stimulate dendrites without ceasing if they were not stopped by certain enzymes that destroy these substances shortly after their release.

Acetylcholine is released also by axons of motor neurons, which terminate on muscle cells. Again, there is a small gap between the cells; in this case, they are called neuromuscular junctions. The acetylcholine from the axon stimulates the muscle cell to contract.

Curare, a paralytic poison, interferes with the reaction of acetylcholine with the chemoreceptors and thus prevents it from functioning. Because muscles then are not stimulated, they do not contract but become paralyzed. Strychnine is a poison that has an opposite effect: it decreases resistance at synapses and thereby causes convulsive muscle contraction.

A single impulse arriving at a synapse is not likely to result in transmission across the synapse, but several impulses arriving in close succession often result in transmission. One impulse probably fails to cause the production or release of enough neurohumor to stimulate the next neuron in the pathway, but several impulses may produce enough for stimulation. This phenomenon is known as summation. Because several axons from different neurons may terminate in a single synapse, summation can also result from the simultaneous arrival of several impulses from the several axons.

Inhibition occurs when one impulse cancels out another impulse arriving at the synapse at the same time. Fortunately, a person rarely is conscious of

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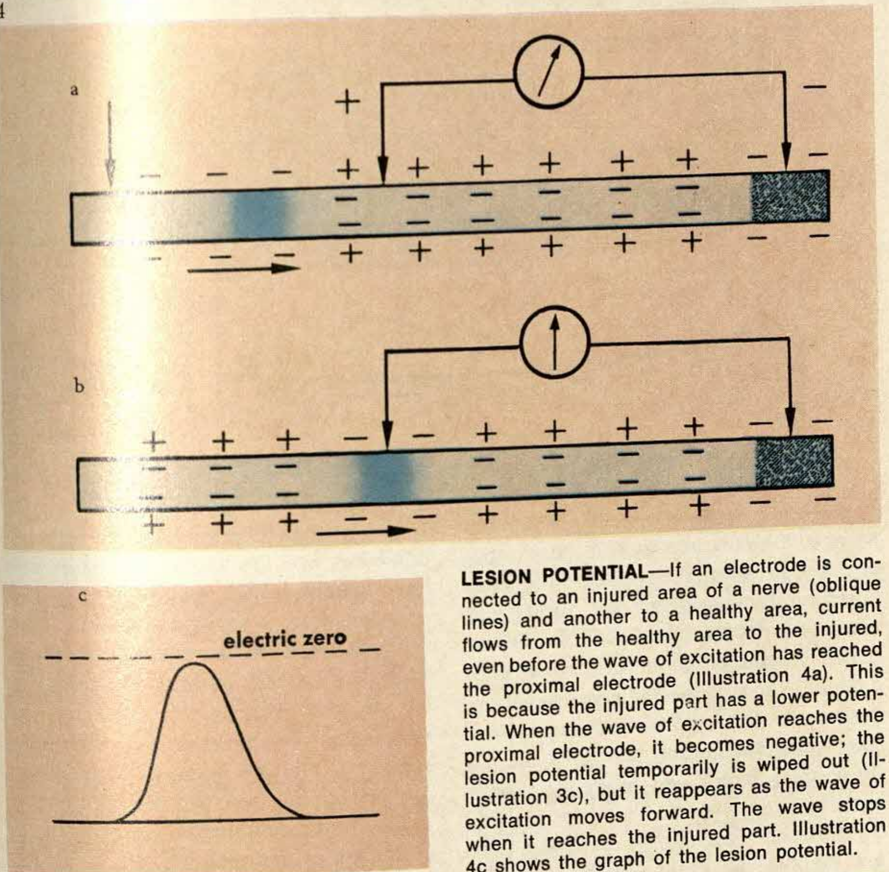

LESION POTENTIAL—If an electrode is connected to an injured area of a nerve (oblique lines) and another to a healthy area, current flows from the healthy area to the injured, even before the wave of excitation has reached the proximal electrode (Illustration 4a). This is because the injured part has a lower potential. When the wave of excitation reaches the proximal electrode, it becomes negative; the lesion potential temporarily is wiped out (Illustration 3c), but it reappears as the wave of excitation moves forward. The wave stops when it reaches the injured part. Illustration 4c shows the graph of the lesion potential.

CONDITION OF EXCITATION IN MYELINATED FIBERS—In myelinated fibers (Illustration 5), the myelin sheath that encloses the axis cylinder process is constricted at certain points called the nodes of Ranvier. Action potential can be measured only in the vicinity of these nodes, the other areas being covered by the myelin sheath, which acts as an insulator and makes them only slightly excitable. The result is that the nervous excitation jumps from one node of Ranvier to another. In this system, only the nodes generate the action potential.

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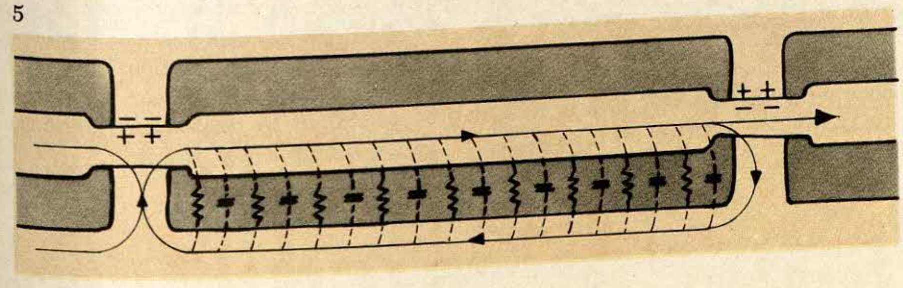

CONDITION OF EXCITATION IN NONMYELINATED FIBERS—When in a state of rest, the outer surface of the nerve fiber is electrically more positive than the inner part. The application of a stimulus (shaded area) causes a flow of ions across the membrane and results in a temporary inversion of polarity, the inside of the cell becoming more positive than the outside. This produces an action current that moves inward at the stimulated area and outward a short distance ahead. The movement of this cyclic current along the fiber is the passage of an impulse along the fiber.

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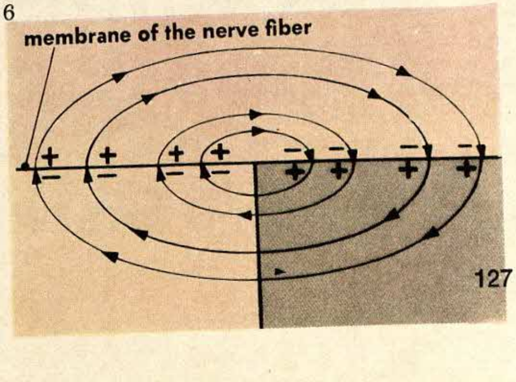

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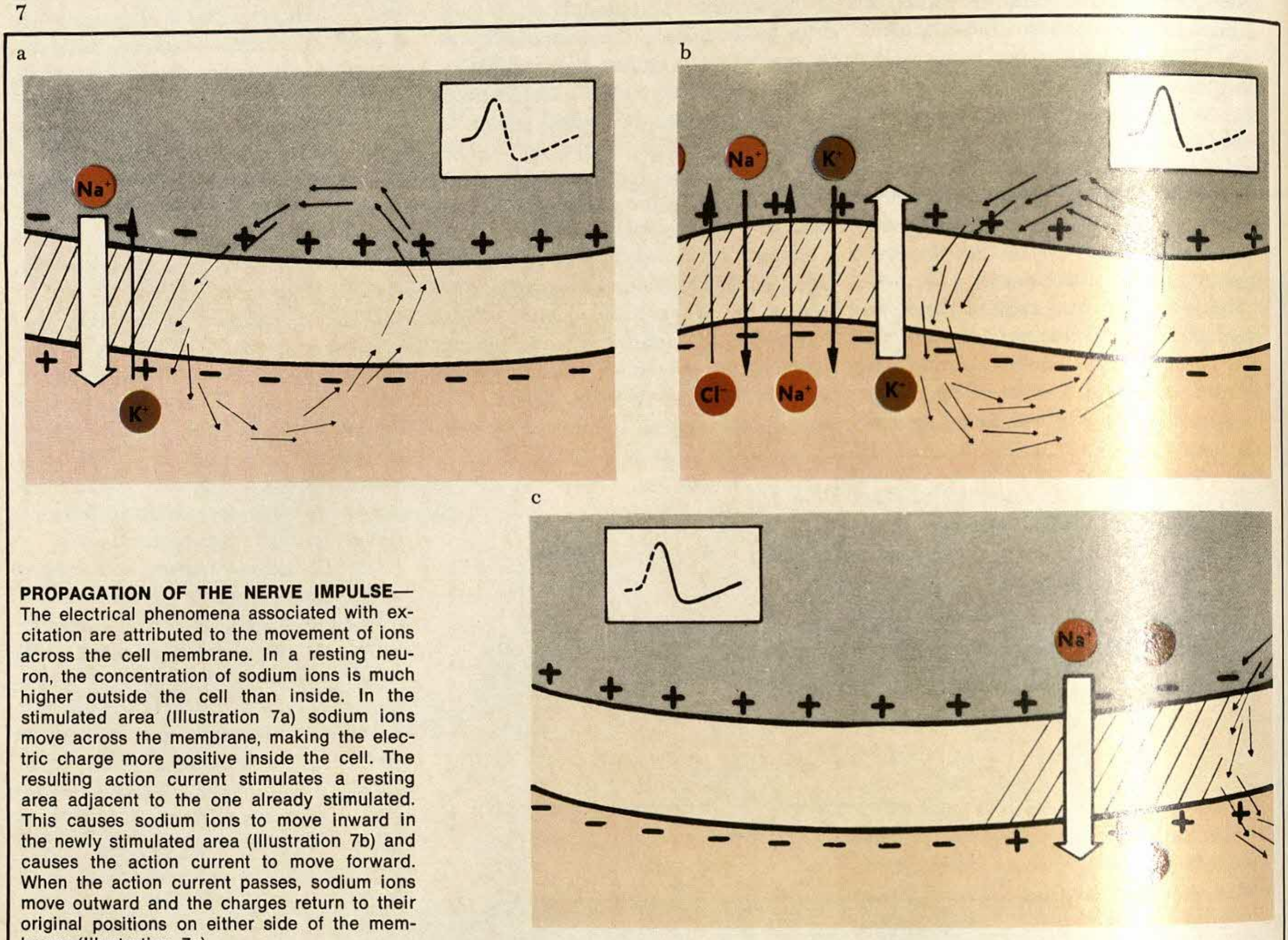

PROPAGATION OF THE NERVE IMPULSE— The electrical phenomena associated with excitation are attributed to the movement of ions across the cell membrane. In a resting neuron, the concentration of sodium ions is much higher outside the cell than inside. In the stimulated area (Illustration 7a) sodium ions move across the membrane, making the electric charge more positive inside the cell. The resulting action current stimulates a resting area adjacent to the one already stimulated. This causes sodium ions to move inward in the newly stimulated area (Illustration 7b) and causes the action current to move forward. When the action current passes, sodium ions move outward and the charges return to their original positions on either side of the membrane (Illustration 7c).

all the stimuli impinging on his neurons. Total involvement in a good book or an exciting movie, for example, can make one unaware of the sound of nearby traffic.

Facilitation or reinforcement is an effect that impulses have on subsequent impulses following the same pathway. The first impulse makes easier the passage of a second impulse, the second makes easier the third, and so forth. This explains why repetition aids memorization and creates habits that require little or no thought.

THE REFLEX ARC

The simplest nerve pathway in the body of advanced animals such as mammals is the reflex arc, which consists of three neurons, each of a different type. The first neuron in the reflex arc is a sensory, or afferent, neuron. Its dendrite terminates in the skin, in a special sense organ, or even in internal organs of the body where it is stimulated by appropriate changes in its environment. The sensory neuron transmits the impulse initiated by a stimulus to a connector (or association) neuron in the central nervous system. The connector neuron transmits the impulse to a motor (or efferent) neuron and then to a muscle that is stimulated to contract. This simple pathway need not involve the brain and does not require thought. The sensory neuron may run, for example, from the foot to the spinal cord; the connector neuron may lie in the spinal cord; and the motor neuron may run from there back to the foot. If the foot is tickled, the reflex arc permits the foot to be withdrawn without conscious effort.

This does not mean that reflex reactions are performed by a person without his knowledge. Because many axons and dendrites are branched, one axon may have synapses with dendrites of several neurons, and several axons may have synapses with the same dendrite. If the axon of a sensory neuron in a reflex arc has synapses with several connector neurons, some of which synapse with other connector neurons leading to the brain, the person can perceive the stimulation.

The brain contains an amazing array of connector neurons. Their number has been estimated at 14 billion, and the number of possible synapses is astronomical. The function of these many neurons and synapses is to receive impulses and sort them out in such a way that the muscles and glands are stimulated to act only at appropriate times and with proper coordination. Furthermore, some acquired functions are localized in one or the other hemisphere of the cerebrum: in right-handed persons, the left hemisphere is dominant.

RECEPTORS AND PHOTORECEPTORS | classification and function

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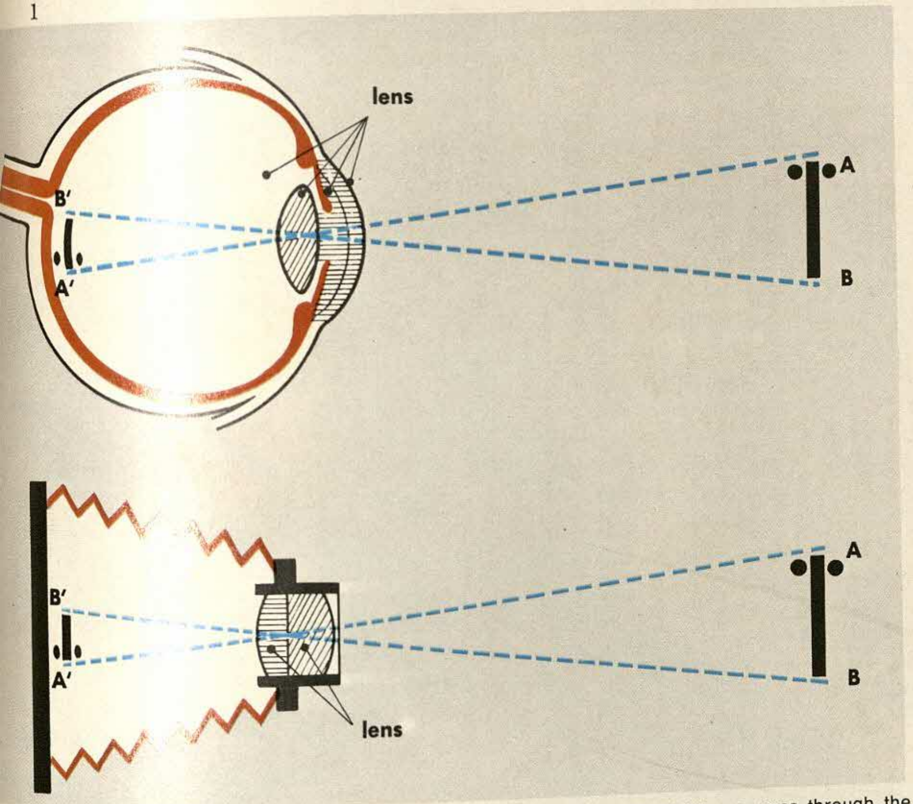

FORMATION OF IMAGES—The eye of a vertebrate often is compared to a camera, and it is true that images are formed according to the laws of geometrical optics. An object **AB** forms an image **A′B′**, smaller and upside down, on the retina; the light rays pass through the cornea and the crystalline lens (which together correspond to the camera lens) and impinge on the retina (which corresponds to the film).

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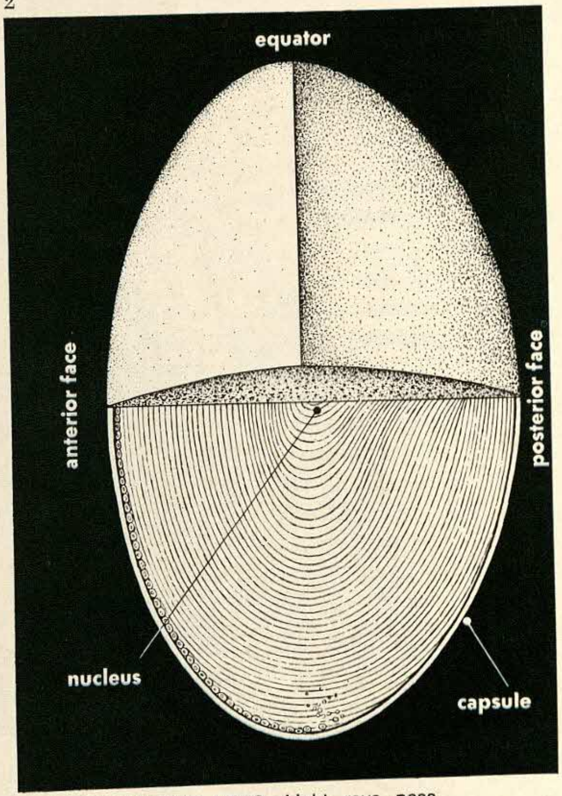

THE CRYSTALLINE LENS—Light rays pass through this transparent lens situated behind the iris. The rays are focused on the retina where they produce an image. The bottom half of the lens in this illustration is dissected.

All organisms receive stimuli from their environments—and all organisms respond to such stimuli. In unicellular forms the single cell is the receptor of stimuli. In multicellular organisms, only certain specialized cells of the nervous system are sensitive to stimuli. Often these cells form special receptors, such as the eye or the taste buds of the tongue.

Specialization has reached such a high level that receptors have extraordinary powers of selectivity. Sound receptors in the ear, for example, are sensitive to variations in air pressure that would be incapable of stimulating any other kind of receptor, such as the eyes. Light rays stimulate the retina of the eye but do not affect the ear or the taste buds of the tongue or the olfactory sense cells in the upper nasal cavity.

In general, the most highly specialized receptors are found in the most highly evolved organisms. The eye of a flatworm, for example, is sensitive to light intensity, but it cannot form an image as the human eye does. In humans and other vertebrates, each receptor is associated with its corresponding muscles by way of nerve cells of the central nervous system. This specialization tends to guarantee an appropriate response to any given stimulation of a receptor.

CLASSIFICATION OF RECEPTORS

The early classification systems divided the senses into five types: touch, taste, sight, smell, and hearing. These senses correspond to the parts of the body that obviously receive these stimuli: skin, tongue, eyes, nose, and ears. More recently, additional receptors have been discovered; some of these are sensitive to heat, cold, pain, motion, equilibrium, hunger, thirst, and kinesthesis (a sense of muscle contraction).

Receptors are classified according to the stimuli to which they are sensitive. Photoreceptors are those that are sensi-

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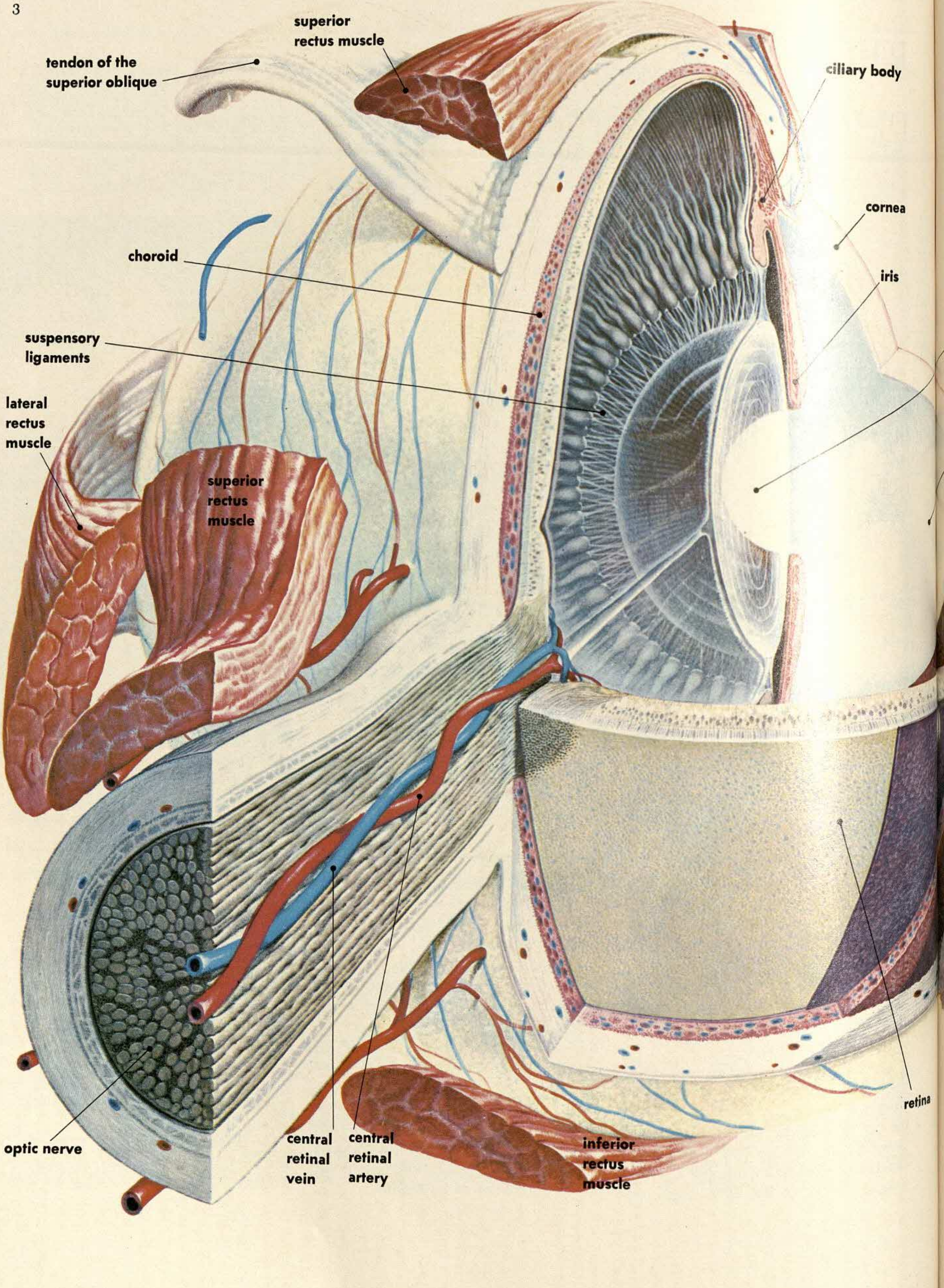
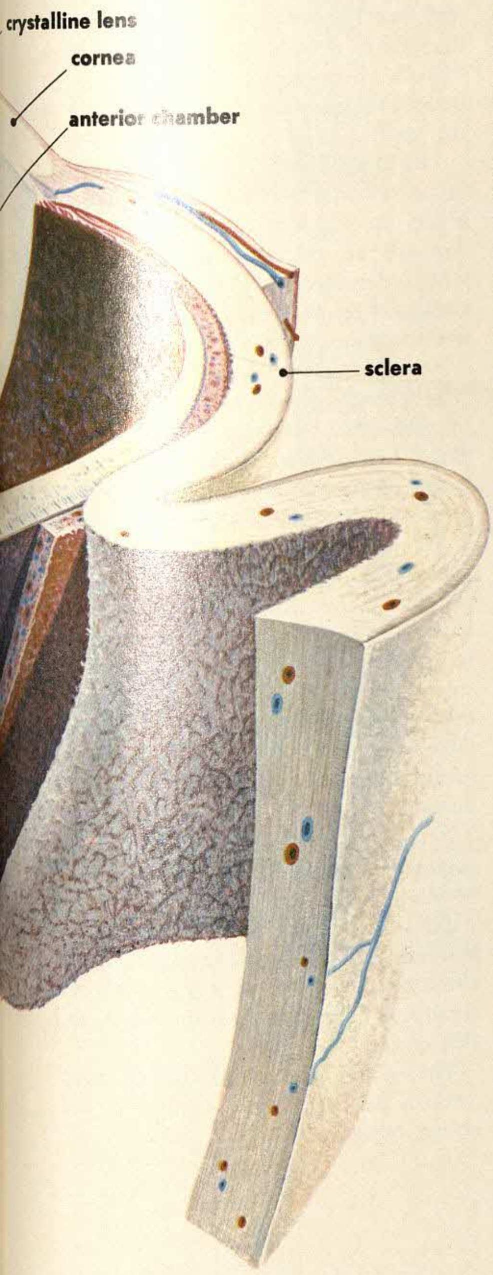

tendon of the superior oblique
superior rectus muscle
ciliary body
cornea
iris
choroid
suspensory ligaments
lateral rectus muscle
superior rectus muscle
optic nerve
central retinal vein
central retinal artery
inferior rectus muscle
retina

THE HUMAN EYE—The illustration shows a human eye seen from the rear. Note the muscles of the eyeball, the three layers that form the outer part of the eyeball, and the optic nerve with its central retinal vein and artery. Part of the eyeball has been cut away to show the anterior chamber of the eye, the iris, the crystalline lens, and the ciliary body. The crystalline lens and the cornea together serve to focus the image. The iris acts as a diaphragm and regulates the amount of light received by the retina.



tive to light; they include the eyes of most animals, the eye spots or pigment spots of many protozoa, and some isolated, light-sensitive cells in certain multicellular animals. Chemoreceptors are those that are sensitive to chemical compounds; in human beings these include the taste buds of the tongue and the olfactory membranes of the nose. Both are sensitive to substances in solution; substances reaching the nose in gaseous form become dissolved in the moisture on the olfactory membranes. Among the invertebrates, the clearest distinction between taste and smell can be made in insects; and there is evidence that worms and gastropods reject bitter substances but accept sugars added to their food. Contact chemoreceptors in insects are located on hairs of the legs and mouth parts. Localized stimulation of the hairs with sugar solution induces extension of the proboscis. When salt is added to the sugar solution, the response may be inhibited. There is no single sensory nerve for taste in vertebrates nor is there a simple relation between chemical composition and taste quality except in the case of acids. Of the inorganic salts, only sodium chloride yields a purely saline taste. Bitter and sweet tastes occur in many chemical classes. Taste is not flavor, which is a composite of pressure, temperature, pain, and odor as well as taste. The distinctive flavors of food are known largely through the sense of smell. The olfactory component in flavor can be demonstrated by closing the nostrils while tasting food. Thermoreceptors in the skin are nerve endings that are sensitive to heat or cold. Touch and pressure are also perceived by nerve endings in the skin; these are called tangoreceptors. Sound is perceived in phonoreceptors; in human beings these are certain cells in the inner ear. In the middle ear are statoreceptors—organs of equilibrium—which transmit information to the brain about the position of the head and the direction of its movement.

PHOTORECEPTORS AND THE EYE

The function of the photoreceptors is to absorb light and transmit this information to an appropriate part of the body—which, in most animals, is the brain.

Many of the lower animals are characterized by diffused sensitivity to light, because the surface of the animal's body contains photosensitive pigment cells. Sea anemones, for example, respond to illumination by a partial contraction of the longitudinal muscles that elongate their bodies. In darkness the circular muscles contract and cause the bodies to shorten. Earthworms also have photoreceptors in the epidermis.

Other animals have simple eyes with photosensitive cells, but no lenses. The planarian is a flatworm that has two such eyes in its head (Illustration 4a). Some bivalve mollusks have small photoreceptors on their mantle edges or their siphons. These receptors, called ocelli, are pigmented, and in most species they lack lenses. Ocelli are sensitive to changes in light intensity, but they do not form images.

The nautilus is a mollusk with an eye that probably forms images. It has a small pupil that probably functions like the opening in a pinhole camera and focuses light on a retina (Illustration 4c). Some mollusks, such as the octopus and squid, have eyes equipped with lenses that are believed to have poor focusing power; their pupils accommodate to different light intensities by changing size.

Mammals and other vertebrates have more highly evolved eyes; indeed, some possess very acute vision. The eye of a mammal is surrounded typically by three concentric coats or layers: an outer layer, the sclera, that is made of fibrous connective material and protects the eyeball; an intermediate layer, the choroid or choroid coat, that is vascular and contains blood vessels and some pigmented cells; and an inner layer, the retina, that consists of nerve cells, some of which are photosensitive. These layers surround nearly the entire eye, but they do not cover the front of the eye.

The cornea is a continuation of the sclera; it encloses the front part of the eye. A short distance behind the cornea is the crystalline lens, which is held in place by a ring of suspensatory ligaments. The cornea and the lens both contribute to the focusing of light rays on the retina.

In front of the crystalline lens is the iris, a diaphragm that regulates the amount of light that reaches the retina. In the center of the iris is an opening, the pupil. The size of the aperture of the pupil increases when light intensity is low, thus increasing the amount of light that reaches the retina. At high light intensities the size of the aperture decreases, thus helping to prevent possible damage to the retina. Within the iris are circular muscles and radial muscles; contraction of the circular muscles causes the constriction of the pupil aperture, and constriction of the radial muscles causes its dilation. The iris muscles are smooth and function under the control of the autonomic nervous system. Dilation and constriction of the pupil aperture are thus involuntary, reflex actions. The muscles of the iris also respond to stimuli caused by emotional states, as is shown by the fact that the pupil dilates at times of intense emotion.

Between the cornea and the iris is the anterior chamber of the eye, which is filled with a liquid called aqueous humor. The chamber behind the lens, the posterior chamber of the eye, contains vitreous humor. These two elements—aqueous humor and vitreous humor—regulate the pressure inside the eye and maintain its shape.

Vision is an enormously complex function. Images are focused onto a sensitive membrane, the retina, which contains large numbers of nerve cells called rods and cones. These cells, which contain photosensitive pigments, are stimulated by light to transmit nervous impulses to other nerve cells, some of which form the optic nerve that extends from the retina to the brain. The retina is the real photosensitive organ capable of transforming radiant energy into nervous energy. Nothing is seen, however, unless the appropriate impulses are received by the brain; thus, both the eye and the brain are necessary for vision.

ACCOMMODATION

The ability to focus on both distant objects and those nearby depends on the ability of the eye to accommodate itself to such viewing. This is accomplished in different ways by different kinds of animals.

In fish, the crystalline lens is shifted forward or backward by contraction or relaxation of an intraocular muscle called the crystalline retractor. In the cuttlefish, a cephalopod mollusk, the entire eyeball changes its shape during accommodation. When the eyeball is shortened, thus bringing the lens closer to the retina, distant objects are seen more clearly. For close vision the eyeball becomes longer, thus increasing the distance between the lens and the retina.

Birds have two methods of accommodation that are useful in rapid flight, when it may be necessary to see clearly both distant and nearby objects almost simultaneously. The changing of the curvature of the lens (described below for mammalian eyes) is one of them. In addition to this, the curvature of the cornea changes, bulging outward for viewing near objects, and flattening for distant ones.

In mammals, accommodation—which is controlled by the autonomic nervous system and is an involuntary reflex—is governed by the elastic properties of the crystalline lens. When in a state of rest, the lens is partially flattened and the eye is accommodated for distant vision. With the lens in this position, light rays emerging from any distant object focus sharply on the retina, but light rays from a nearby object form only a fuzzy image on the retina. When the eye focuses on an object that is close, the lens, being elastic, increases its curvature. This causes a sharp image to fall on the retina. The curvature of the crystalline lens is caused by the relaxation and contraction of the ciliary muscles that control the tension on the suspensatory ligaments that hold the lens in place. Relaxation of the ciliary muscle (which is a smooth muscle) causes flattening of the lens; contraction of the muscles causes bulging of the lens.

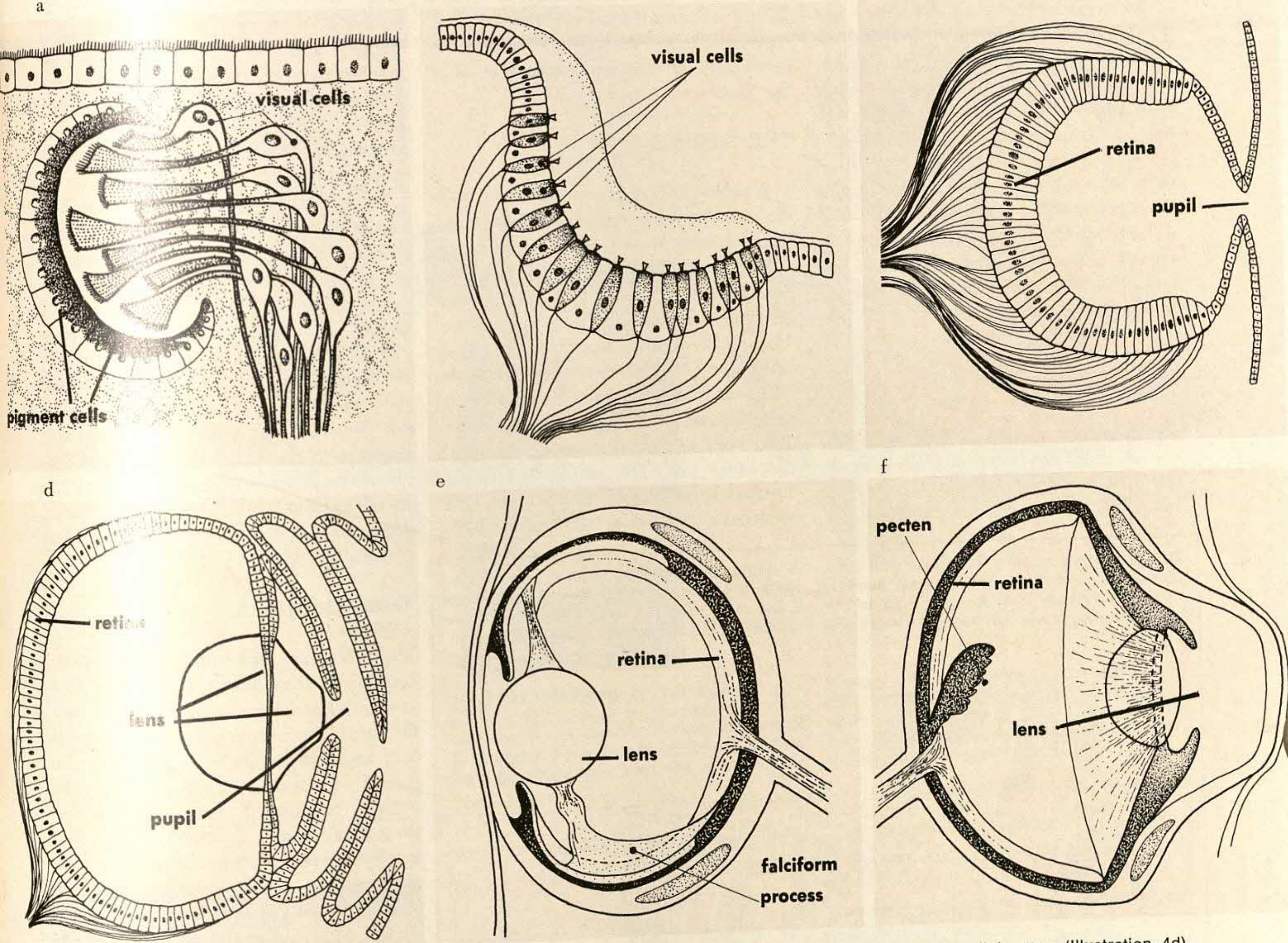
The limit of accommodation is the minimum distance between the eye and the object on which it can focus; this limit depends on the elasticity of the lens, which decreases with increasing age—that is, as people grow older they tend to become more farsighted.

Accommodation also involves the iris, which contracts and partially closes the pupil aperture when the eye is accommodated for close-up vision. This corrects spherical aberration, a type of aberration produced by a lens whose focusing power is different in its central and peripheral zones. This aberration increases in proportion to the size of curvature of the lens; the curvature of the crystalline lens is greatest when the eye is focused on something nearby. The partial closing of the iris permits light rays to pass through the center of the lens only and thus increases the sharpness and clarity of the image.

Accommodation of the eye thus involves the harmonious action of several involuntary muscles: the ciliary muscles, which change the shape of the crystalline lens; and the circular and radial muscles of the iris, which regulate the intensity of light falling on the retina and also correct aberration.

The up-and-down or side-to-side movement of the eyeball is controlled by voluntary muscles.

4



SOME TYPES OF PHOTORECEPTOR—Visual receptors at their simplest consist of single sensitive cells sometimes found in association with pigmented cells. In other cases visual cells and pigmented cells are joined together, forming simple eyes. The eye of a planarian, one of the flatworms, consists of several visual cells in a cup of pigment cells (Illustration 4a). The limpet, a gastropod, has simple eyes in depressions; the retina consists of visual cells and pigment cells (Illustration 4b). The eye of the nautilus, a cephalopod, is similar to that of the limpet, but it is almost completely enclosed; a small opening serves as the pupil (Illustration 4c). The eyes of other cephalopods, such as the octopus and squid, have a lens that focuses light rays (Illustration 4d). The eye of a bony fish contains the falciform process, a connective lamina arising from the choroid and extending into the vitreous humor (Illustration 4e). The eye of a bird (Illustration 4f) also has a special choroid formation, the pecten or comb, whose function, like that of the falciform process, is unknown.

THE EAR | hearing and equilibrium

The ear is generally thought of simply as the organ of the sense of hearing, but this is not its only function. It is also an organ of equilibrium. Parts of the ear are sensitive to sound waves, and other parts play essential roles in awareness of both static and dynamic equilibrium.

The ear consists essentially of three parts: the outer ear, the middle ear, and the inner ear. The outer ear and the middle ear function chiefly by channeling sounds from the outside world to the inner ear, where the actual receptors for sound are located. Here, too, are the organs of equilibrium.

THE OUTER EAR

The outer ear consists of a pinna, which is the expanded portion that projects from the head, and an external auditory canal. The skeleton of the pinna consists only of cartilage. The first 8 mm (about ⅓ in.) of the external auditory canal is surrounded by cartilage; the rest of the canal projects into the temporal bone of the skull.

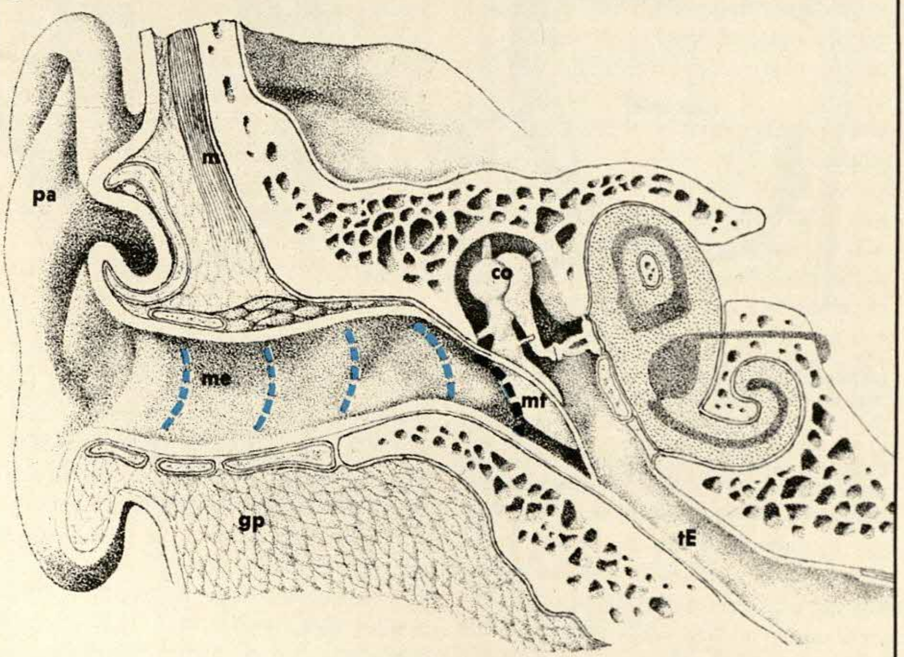
THE MIDDLE EAR

The outer ear is separated from the middle ear by the tympanic membrane, which is also known as the eardrum. It is held in position by a ring of cartilaginous fiber, which locks its outer edge into the tympanic notch in the temporal bone. The middle ear is an air-filled cavity called the tympanic cavity. Opposite the tympanic membrane are two small openings, the oval window and the round window, both of which communicate with the inner ear. The round window is covered by a thin membrane called the secondary tympanic membrane. Spanning the middle ear are three small bones: the hammer (malleus), the anvil (incus), and the stirrup (stapes). The inner surface of the tympanic membrane is attached to the hammer, which articulates with the anvil. The anvil, in turn, articulates with the stirrup, the base of which fits in the oval window.

Opening into the middle ear is the Eustachian tube, which leads from the middle ear to the pharynx and allows the air pressure on either side of the tympanic membrane to become equalized before a dangerous difference in pressure can occur and rupture the membrane. If the Eustachian tubes become blocked, as they may during an infection, they do not perform their function well, and the pressure in the ear becomes uncomfortable. The rapid changes in pressure that occur in aircraft sometimes cause similar discomfort that often can be alleviated by swallowing.

THE EAR—This cutaway illustration shows the outer and middle ear. The external auditory canal **me** extends from the pinna **pa** to the tympanic membrane **mt** and penetrates the temporal bone **t**. The middle ear contains three small bones **co**, and from it extends the Eustachian tube **tE**. Note also the temporal muscle **m** and, below, the parotid gland **gp**.

1

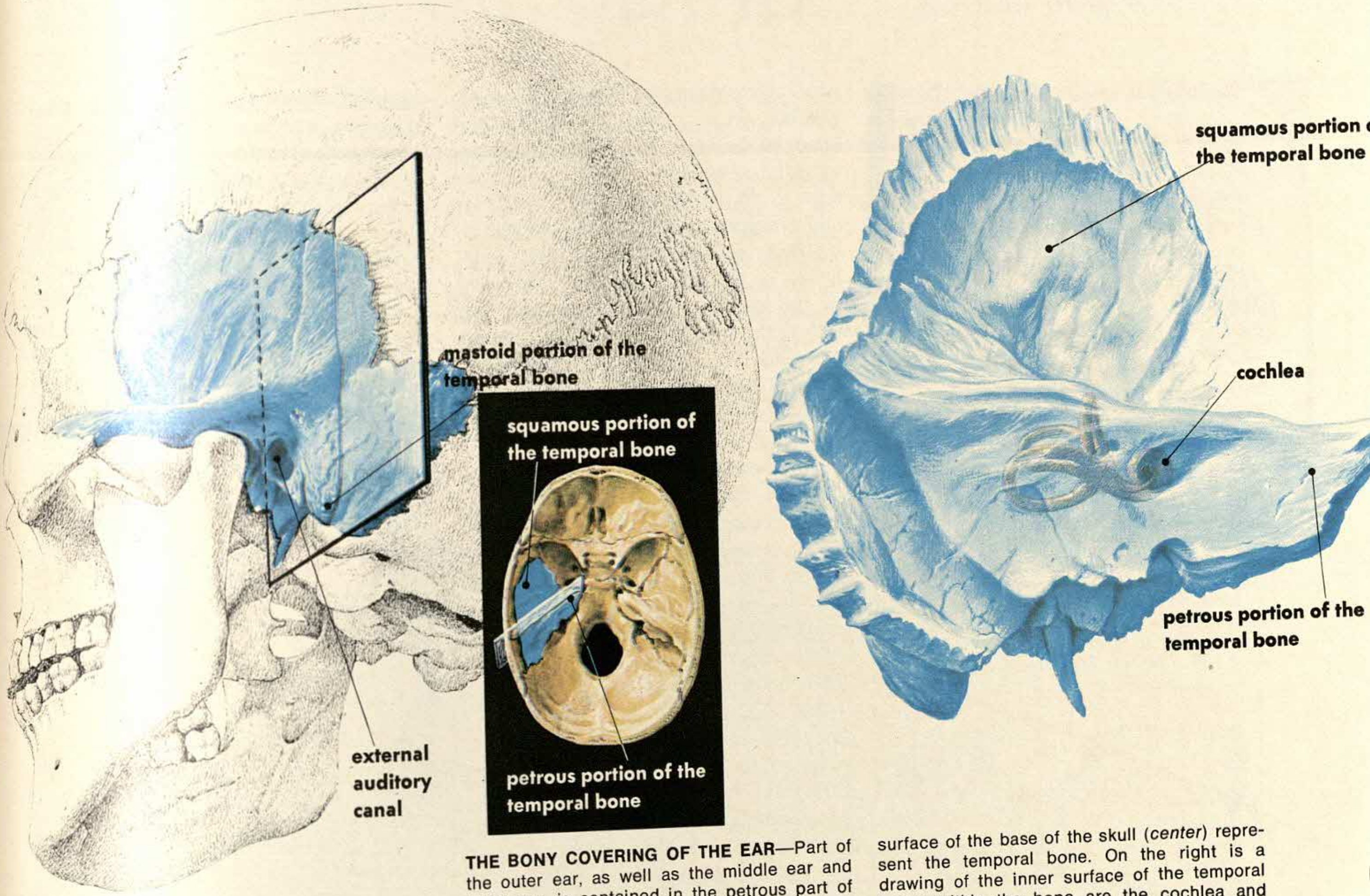


THE INNER EAR

The inner ear, also called the labyrinth, consists of three parts: the cochlea, the vestibule, and three semicircular canals. Of these, the cochlea functions in hearing, and the vestibule and semicircular canals are organs of equilibrium. The cochlea consists of three channels running parallel to each other as they spiral in the manner of a snail shell. The three channels are the vestibular canal, the cochlear duct, and the tympanic canal. At the wide end of the cochlea, the vestibular canal is covered by the oval window, and the tympanic canal is covered by the round window. At the narrow end of the cochlea, the vestibular and the tympanic canals communicate with each other. Both are filled with a liquid called perilymph. The cochlear duct between them contains endolymph.

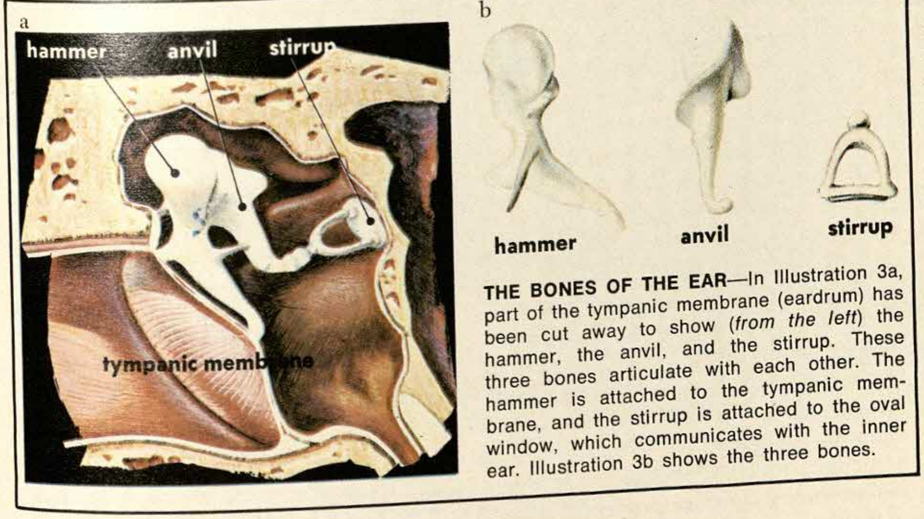
The three channels spiral around a central bony core, the modiolus. Extending from the modiolus is a bony plate that partially separates the tympanic canal from the vestibular canal and the cochlear duct. The basilar membrane

2


mastoid portion of the temporal bone
squamous portion of the temporal bone
petrous portion of the temporal bone
external auditory canal
squamous portion
the temporal bone
cochlea
petrous portion of the temporal bone

THE BONY COVERING OF THE EAR—Part of the outer ear, as well as the middle ear and inner ear, is contained in the petrous part of the temporal bone. The blue-colored sections of the drawings of the skull (*left*) and the inner surface of the base of the skull (*center*) represent the temporal bone. On the right is a drawing of the inner surface of the temporal bone; within the bone are the cochlea and the semicircular canals.

3

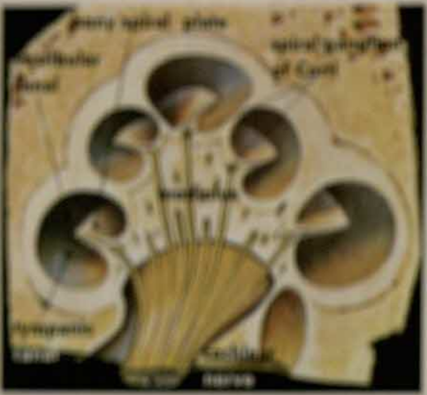


THE BONES OF THE EAR—In Illustration 3a, part of the tympanic membrane (eardrum) has been cut away to show (*from the left*) the hammer, the anvil, and the stirrup. These three bones articulate with each other. The hammer is attached to the tympanic membrane, and the stirrup is attached to the oval window, which communicates with the inner ear. Illustration 3b shows the three bones.

completes the separation. Dividing the vestibular canal from the cochlear duct is Reissner's membrane. On the basilar membrane is situated the organ of Corti, which contains a special group of hair cells that extend into the endolymph of the cochlear duct. Overlying them is the tectorial membrane. The bases of the hair cells are in contact with the dendrites of neurons of the cochlear nerve, a branch of the acoustic nerve. The neurons extend through the basilar membrane, the bony spiral plate, and the modiolus.

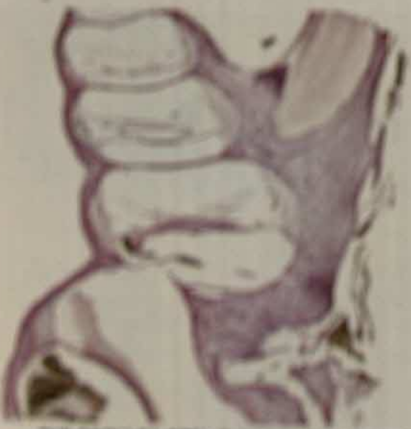
Sound is perceived in the following manner: Sound waves collected by the pinna travel the length of the external auditory canal where they cause the tym-

4



THE COCHLEA—This illustration is a section of the cochlea, a small block of bony tissue containing a spiral canal that winds around a central bony core known as the modiolus. The bony spiral canal is partially divided by a bony plate, also spiral, that projects from the modiolus into the canal. Not shown are the basilar and vestibular membranes that divide the canal into three canals.

5



THE COCHLEA SEEN THROUGH THE MICROSCOPE—Above is a microphotograph of a section of part of the cochlea. The basilar membrane with the organ of Corti can be seen most clearly in the turn of the cochlea nearest the center of the photograph. (96 X)

panic membrane to vibrate. These vibrations set in motion the three small bones of the inner ear. The stirrup transmits the vibrations across the oval window to the perilymph of the vestibular and tympanic canals. From here the vibrations are transmitted to the endolymph of the cochlear duct. Movement of the endolymph stimulates the hair cells in the organ of Corti, which initiates a nervous impulse in the dendrites touching the hair cells. When the impulse reaches the auditory area of the brain, the sensation of sound is perceived.

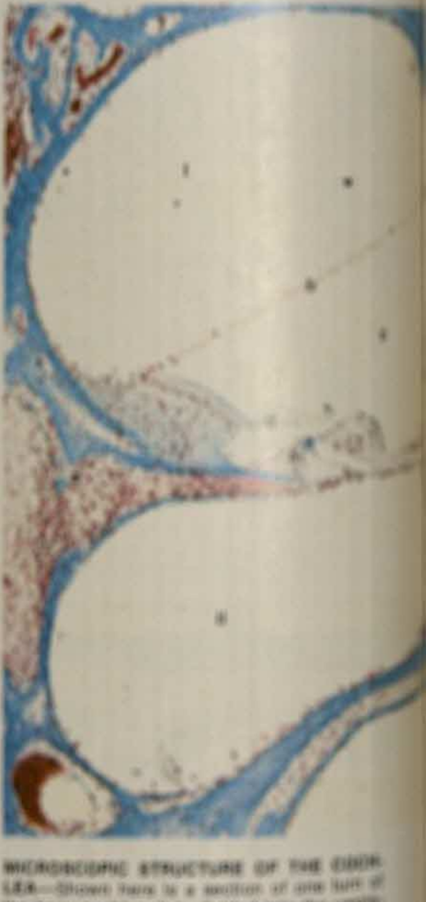
The membrane of the round window is elastic and acts as a sort of safety valve. Because the perilymph is virtually incompressible, whenever the stirrup pushes inward at the oval window, the pressure of the perilymph pushes the round window membrane outward.

The vestibule of the inner ear contains the organs of static equilibrium—the utricle and the saccule. Each of these small chambers contains a bed of hair cells similar to those of the organ of Corti. The hair cells, together with the nerve endings that touch them, are collectively called the macula. Resting on the macula are minute bonelike fragments called otoliths. When the head is in different positions, the pressure exerted by the otoliths on the hair cells is different, and different nerve endings are stimulated. The resulting impulses reaching the brain transmit information about the position of the head.

The semicircular canals of the inner ear are the sense organs of dynamic equilibrium; they are sensitive not only to movement of the head but also to the direction of movement. The three semicircular canals lie approximately perpendicular to each other. Each has a swelling, the ampulla, that contains a tuft of hair cells that contact nerve endings. The hollow semicircular canals are filled with endolymph that is set in motion when the head moves. This stimulates the nerve endings that transmit to the brain the sensation of movement in a particular direction. Because the three semicircular canals are perpendicular to each other, movement of the head in any direction affects each differently. The information reaching the brain from all three canals permits very accurate analysis of the exact direction of movement of the head.

Neurons from the utricle, the saccule, and the semicircular canals form the vestibular nerve, which is one branch (the cochlear is the other) of the acoustic, or eighth cranial, nerve.

6



MICROSCOPIC STRUCTURE OF THE COCHLEA—Shown here is a section of one turn of the bony cochlea. It is divided into the vestibular canal 1 and the tympanic canal 2 by the bony spiral plate 3, which continues as the basilar membrane. The latter bears the spiral organ of Corti 4. This organ is composed of support cells and specific sensory cells. The tectorial membrane 5 covers the organ of Corti. Reissner's membrane 6 forms one boundary of the cochlear duct 7, separating it from the vestibular duct in which it is located.

THE PITUITARY AND THE ADRENAL GLANDS

an extraordinary glandular triangle

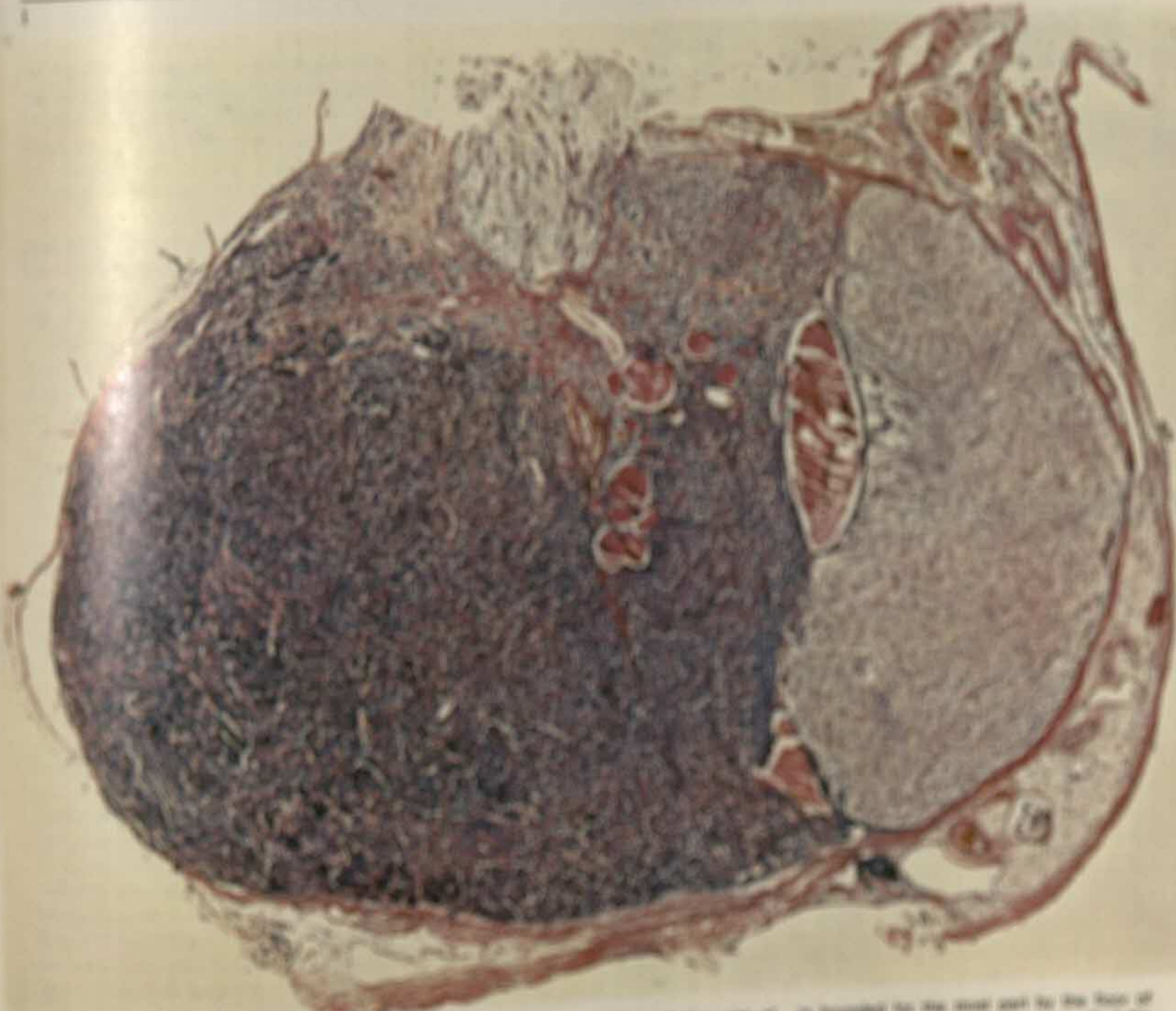
In an organism having many different kinds of tissues and organs, the various parts must function well with each other or the health of the organism will suffer. The function of correlating the activities of the many parts of the human body is carried on by two systems: the endocrine system and the nervous system. The endocrine system exerts its effects on the rest of the body by producing and secreting chemical compounds called hormones.

The endocrine glands are ductless glands; that is, they secrete their hormones directly into the bloodstream, which carries the hormones throughout the body. One endocrine gland, the pituitary, is sometimes called the master gland because it regulates the activities of other endocrine glands. However, the hormones produced by these other glands exert some effect on the pituitary gland, in turn.

THE PITUITARY

The pituitary, or hypophysis, is a small gland that weighs about 0.6 g (about 0.02 oz.) and is situated below the brain in the floor of the skull. The pituitary consists of two parts: the adenohypophysis, which consists of the anterior portion and a small intermediate lobe, and the neurohypophysis, which comprises the posterior portion.

1



LONGITUDINAL SECTION OF THE HUMAN PITUITARY.—The adenohypophysis (or glandular portion) appears at the left, while the neurohypophysis (or nervous portion) is on the right. The peduncle of the pituitary is at the top. This connects the nervous portion of the pituitary to the diencephalon, one of the most important parts of the brain.

The pituitary is enveloped by a fibrous covering formed from the dura mater (a portion of which appears at the extreme right) and is sheltered in the hollow of the pituitary, which is bounded for the most part by the floor of the skull. Lesions that in some way affect the function of the pituitary can cause diabetes insipidus, and adiposogenital dystrophy, or Fröhlich's syndrome, among others. [illegible]

THE NEUROHYPOPHYSIS

The neurohypophysis is composed essentially of unmyelinated nerve fibers, among which numerous neuroglial cells (pituicytes) are scattered. It functions in close relationship with a portion of the brain, the hypothalamus. For this reason, the two together are more properly referred to as the hypothalamo-neurohypophysis system. This system produces two hormones, oxytocin and vasopressin; the latter is also called the antidiuretic hormone, or ADH. Both are quite similar chemically, having simple structures formed of eight amino acids; their functions partially overlap.

PRODUCTION AND CIRCULATION

Oxytocin and vasopressin are synthesized in the hypothalamus, from which they move through nerve fibers into the posterior pituitary, where they are stored. Although very little is known about the mechanism that controls the release of pituitary hormones, it is believed to be of nervous origin. It is known that their release can be triggered by a number of stimuli, both chemical and physical: nicotine, anesthetics, emotions (especially those of a sorrowful nature), and muscular activity. Alcohol, however, restricts the release of hormones from the hypophysis.

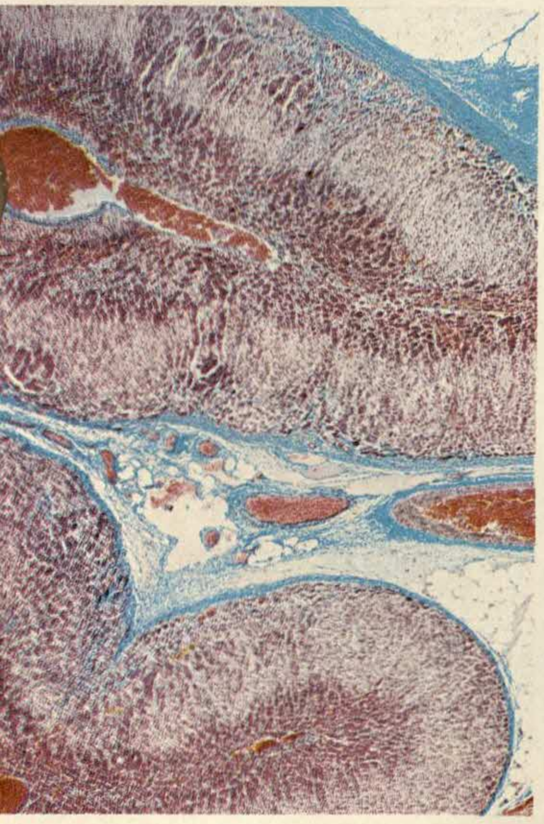
Oxytocin stimulates contractions of the uterus during birth and increases the ejection of milk by the mammary glands. It functions, therefore, both during and after birth.

Vasopressin has two functions: it stimulates the constriction of muscles of small arteries and capillaries, thus causing an increase in blood pressure, and it has an antidiuretic effect on the kidneys. Each day, the kidneys filter waste materials from 180 liters (about 190 qt) of plasma. More than 99 percent of this liquid is reabsorbed by the kidney tubules, and about ½ to 1 liter (about ½ to 1 qt) of urine is eliminated. The reabsorbed material is mostly water. Vasopressin acts on the kidney tubules by increasing their permeability, thus stimulating them to absorb the water—preventing excessive water loss from the body. The rate of secretion of vasopressin by the neurohypophysis is not constant but varies according to the body's need to excrete or conserve water. The condition known as diabetes insipidus is caused by an abnormal deficiency of vasopressin and results in excretion of excessive quantities of urine.

Even a slight imbalance in the water-salt ratio of the body is registered by specialized cells called osmoreceptors. Some of these exist in the carotids (the arteries that supply blood to the brain). The osmoreceptors are capable of immediately signaling the hypothalamus to secrete more or less vasopressin. Another regulatory factor is the nervous system, which acts directly on the hypothalamus. Physical pain and emotions can cause an increase in the secretion of vasopressin.

AN ADRENAL GLAND—The adrenal glands are located on the kidneys. The cortex, the medulla, connective tissue, and blood vessels are shown here.

2



THE ADENOHYPOPHYSIS

The adenohypophysis has a structure similar to that of the other glands; it consists of cells closely associated with the mass of capillaries that provide it with an abundant blood supply. So far, six hormones of the adenohypophysis have been isolated. Five are adenotrophic hormones, which control the activity of other glands of the endocrine system, while the sixth hormone—the growth hormone STH—is the only one that acts without the intervention of other glands.

ADENOTROPHIC HORMONES AND STH

The adenotrophic hormones secreted by the adenohypophysis are the gonadotrophic hormones: FSH, the follicle-stimulating hormone; LH, the luteinizing hormone; LTH, the luteotrophic hormone, all of which control the gonads; ACTH, the adrenocorticotrophic hormone; TSH, the thyroid-stimulating hormone; and STH, the somatotropic hormone.

The growth hormone, STH, causes an increase in weight in developing individuals and simultaneous growth of bones and muscle. STH favors the synthesis and formation of deposits of proteins and, by its action on the pancreas, affects the carbohydrate metabolism of the body. An excess of STH during the growing years causes gigantism; a lack causes dwarfism.

The hormone ACTH, which is secreted into the blood by the pituitary, acts on the adrenal glands, favoring the formation and the secretion of glucocorticoids, notably cortisone. The principal function of cortisone is regulation of the metabolism of sugars. ACTH and glucocorticoids are involved in a feedback mechanism that maintains normal concentrations of these hormones in the body. ACTH stimulates the adrenal glands to secrete glucocorticoid hormones; but when the concentration of these hormones rises, they inhibit the secretion of ACTH from the adenohypophysis. As the concentration of ACTH falls, the adrenal glands are no longer stimulated to secrete glucocorticoids;

consequently, their concentration falls. This releases the adenohypophysis from inhibition and favors the liberation of ACTH again.

The other adenotrophic hormones are involved in similar feedback mechanisms with their target organs.

RELEASING FACTORS

A study of the effect of the action of endocrine glands has led to the conclusion that additional regulating mechanisms exist. In fact, groups of nerve cells in the hypothalamus liberate substances that have a specific action on the pituitary, and these substances are called releasing factors. The corticotrophin releasing factor (CRF), for example, which reaches the pituitary from the hypothalamus, stimulates the release of ACTH into the blood stream.

ADRENAL GLANDS

The adrenal, or suprarenal, glands are two dark gray bodies situated on the upper ends of the kidneys. Like the pituitary, these two organs have two parts that are structurally and functionally differentiated: a central portion, the medulla, and the cortex that surrounds the medulla.

THE ADRENAL MEDULLA

The adrenal medulla is composed of elongated, polygonal cells closely associated with many blood vessels. It secretes both adrenaline (epinephrine) and noradrenaline (norepinephrine)—about five times more of the former than of the latter. However, the concentration of noradrenaline in the blood is five times greater than that of adrenaline; this is because noradrenaline is also secreted by sympathetic nerves.

ADRENALINE AND NORADRENALINE

Adrenaline acts in different ways on several parts of the body. Its principal action is on the circulatory system and the muscles. Adrenaline increases the rate of heartbeat, causes dilation of arterioles in the muscles, brain, and heart, and causes the constriction of surface arteries. It also causes the relaxation of the smooth muscles of the stomach, intestines, bronchioles, bladder, and gastric sphincters, and it constricts the dilating muscles of the pupils and the erector muscles of the hair. Adrenaline also has a hyperglycemic function; that is, it causes the breakdown of glycogen to glucose in the muscles and liver.

Noradrenaline acts on the circulatory system, but it often has an opposite action to that of adrenaline—it causes a decrease in the heartbeat, reduces the flow of blood to the skeletal muscles, and slightly increases the supply of blood to the skin.

THE ADRENAL CORTEX

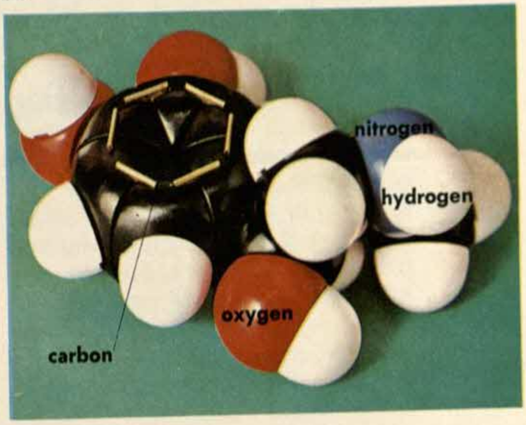
The adrenal cortex, which in the adult makes up about 80 percent of the adrenal gland, has three different cell zones. The outermost is the glomerular zone; it is composed of small round cells with dark nuclei and little cytoplasm, and it contains granular matter. The fasciated zone and the innermost reticular zone are formed of large cells with vesicular nuclei. In the fasciated zone these cells are arranged in radial columns, while in the reticular zone the cells have a netlike arrangement. Of the many hormones produced by the adrenal cortex (more than thirty have been extracted), all but seven are intermediate products of their synthesis.

The hormones of the adrenal cortex can be divided into two groups on the basis of their action. The first group contains the mineralocorticoids, so called because they regulate the balance of several minerals in the body, especially sodium and potassium. They include 11-deoxycorticosterone (DOCA), corticosterone, 11-dehydrocorticosterone, and aldosterone.

The second group contains the glucocorticoids, which include 11-deoxycortisol, cortisol (hydrocortisone), which alone constitutes 70 percent of the secretion of the adrenal cortex, and cortisone. The glucocorticoid hormones regulate the metabolism of carbohydrates; they cause conversion of liver glycogen to blood glucose, and they increase synthesis of carbohydrates from proteins and fats. These hormones also cause an increase in the gastric secretion of hydrochloric acid and pepsinogen.

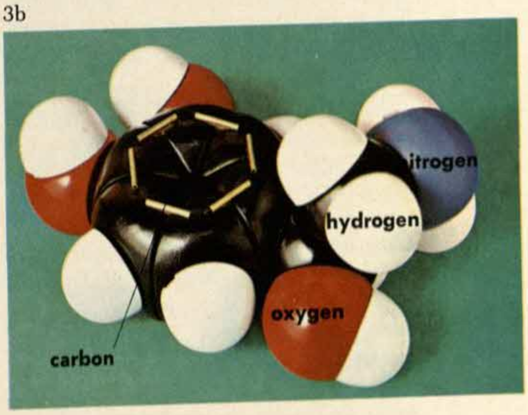
Tissue reactions such as hypersensitivity, allergic states, and collagen diseases benefit from treatment with cortisone and hydrocortisone. Patients who lacked adrenal secretion—a condition known as Addison's disease—nearly always died from it before 1930. Then an extract of the adrenal gland was first used as substitution therapy. Administration of cortisone or hydrocortisone and small amounts of deoxycorticosterone or aldosterone to patients suffering from deficient adrenal cortical functions permits them to live normally and even to undergo surgery.

3a



THE ADRENAL HORMONES—Illustration 3a represents the molecular structure of adrenaline, while Illustration 3b shows that of noradrenaline. These two hormones often have opposite functions.

3b



THYROID, PARATHYROID, AND PANCREAS

remarkable hormone producers

The ability of any gland to produce hormones depends on the genetic, or hereditary, makeup of the entire organism. The genetic material that determines this makeup is deoxyribonucleic acid (DNA), which controls the synthesis of hormones and other chemical compounds as well. A change, or mutation, in the structure of DNA can affect the ability to produce hormones, causing either an excess or a deficiency of the hormone. This ordinarily has a negative effect on the well-being of the individual.

Some hormones, such as those produced by the thyroid gland, are known to function by affecting the DNA-controlled synthesis of other compounds. The thyroid hormonal complex is known to be one of these.

THE THYROID GLAND

The thyroid gland, which is located in the anterior part of the neck, is shaped somewhat like the letter H, with the transverse bar in a very low position. Its weight varies from 20 to 40 g (about 0.7 to 1.4 oz), and it is usually larger in women than in men. The thyroid hormonal complex consists of five hormones that are similar in their chemical structure: thyroxine, thyrocalcitonin, diiodothyronine, and two types of triiodothyronine.

Triiodothyronine and thyroxine have the same function; they increase the rate at which foods are oxidized, and therefore they increase the rate of oxygen consumption. These hormones differ structurally, however, since the triiodothyronine molecule contains three atoms of iodine and the thyroxine molecule contains four iodine atoms. (For this reason thyroxine is also known as tetraiodothyronine.)

Thyrocalcitonin is a hormone that lowers the concentration of calcium in the blood when it becomes too high. It is believed that thyrocalcitonin is secreted by the thyroid gland in response to stimulation by the parathyroid glands.

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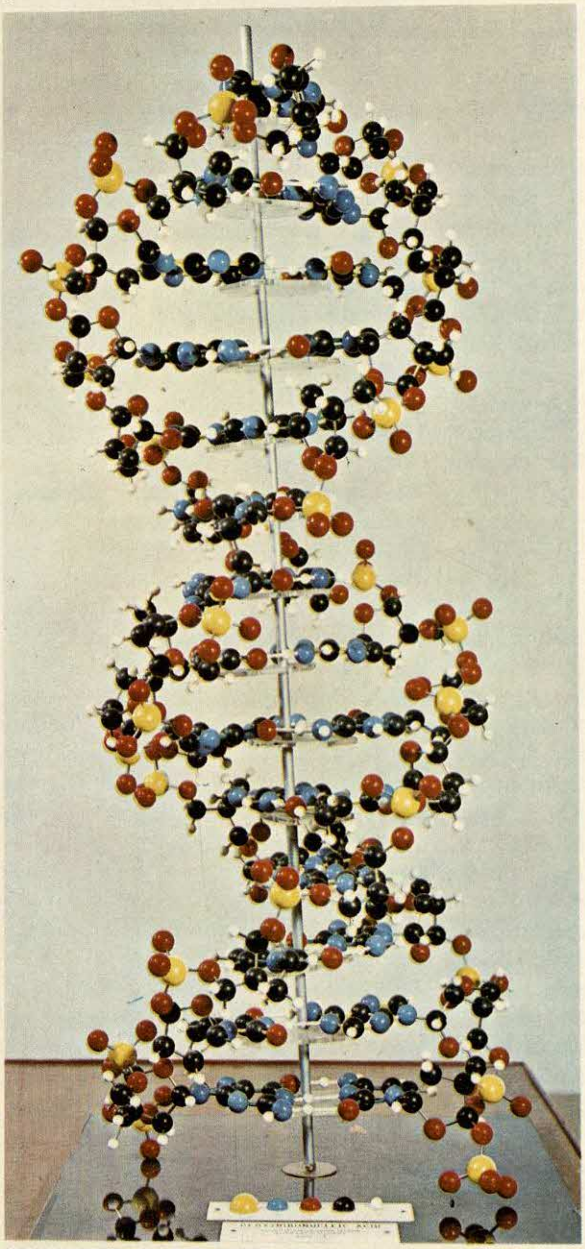
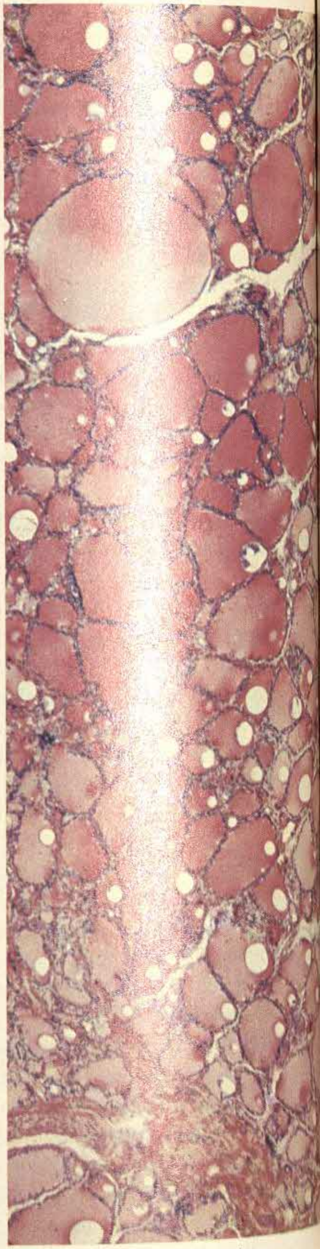


DEOXYRIBONUCLEIC ACID—This molecular model shows the helical structure of DNA. Recent experiments indicate that the thyroid hormone complex acts on the nucleic acids. It has been demonstrated that the quantity of RNA increases after the administration of the thyroid hormone. In the model, phosphorus is represented by yellow, nitrogen by blue, carbon by black, oxygen by red, and hydrogen by white.

2



SECTION OF THE THYROID—This microscopic view reveals the follicular structure of the thyroid. The follicles contain an amorphous substance in which the four thyroid hormones, similar in their chemical structure, are present. Triiodothyronine and thyroxine have the same function: they activate the oxidizing reactions in the cell, increasing the consumption of oxygen. (68 X)

CONTROL AND FUNCTIONS OF THE THYROID HORMONAL COMPLEX

The secretion of thyroid hormones is regulated by the thyrotrophic hormone (thyroid-stimulating hormone, or TSH), which is secreted by the pituitary gland. When the body needs more thyroid hormones, the hypothalamus releases TRF, which acts on the pituitary, causing it to secrete TSH, which causes the thyroid gland to secrete thyroid hormones.

Thyroid hormones affect body development and the metabolism of sugars, proteins, and fats. Recent experiments indicate that thyroid hormones exert their effects by acting on the nucleic acids (RNA and DNA); it has been demonstrated that the quantity of RNA increases after the administration of thyroid hormones. Since RNA is involved in most body processes, it is no wonder that the thyroid hormonal complex has greatly varied functions and is essential for normal life.

The control and functions of thyroid hormones are good evidence that the proper function of the organism is both complex and simple, for the functions of all the parts of a healthy individual are perfectly integrated.

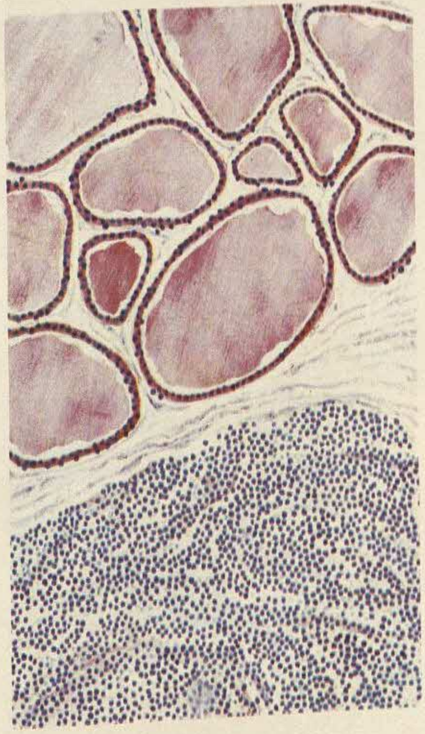
THE PARATHYROID GLANDS

The parathyroid consists of four small glands, each having an elongated oval form. The entire parathyroid weighs about 0.17 g (about 0.006 oz). The parathyroid glands lie on the posterior surface of the thyroid (two above and two below), and they secrete a hormone, probably proteinaceous, whose function is principally that of removing calcium from the bones and circulating it in the blood.

Minute quantities of calcium and phosphates are free in the form of ions in the body fluids. For the most part, these two substances are combined as calcium phosphate, which is present mainly in the bones. The concentrations of calcium ions and phosphate ions in solution bear a relationship to each other: as the concentration of one increases, the concentration of the other decreases. Some authorities believe that the parathyroid hormone influences the concentration of phosphate and affects its rate of excretion through the kidneys. Others believe that this hormone regulates the concentration of calcium in the blood. Both theories have considerable support. The pituitary regulates the activity of the parathyroids, but it has not yet been determined whether this activity is regulated by a particular hormone, as it is in the case of the thyroid gland.

SECTION OF THE THYROID AND PARATHYROID—The drawing shows the microscopic structure of the thyroid (above) and the parathyroids, the four endocrine glands that lie on the posterior surface of the thyroid. The parathyroids secrete the parathyroid hormone, whose principal function is maintaining the balance of phosphorus and calcium in the bloodstream, the bones, and other parts of the body.

3



THE ISLETS OF LANGERHANS

The pancreas, a large digestive gland behind the stomach and somewhat parallel to the duodenum, contains two types of cells. The cells of one type secrete digestive enzymes into the small intestine. Scattered among these cells are clusters of glandular cells, known as the islets (or islands) of Langerhans. Usually round but occasionally elongated, the islets of Langerhans secrete two very important hormones, insulin and glucagon.

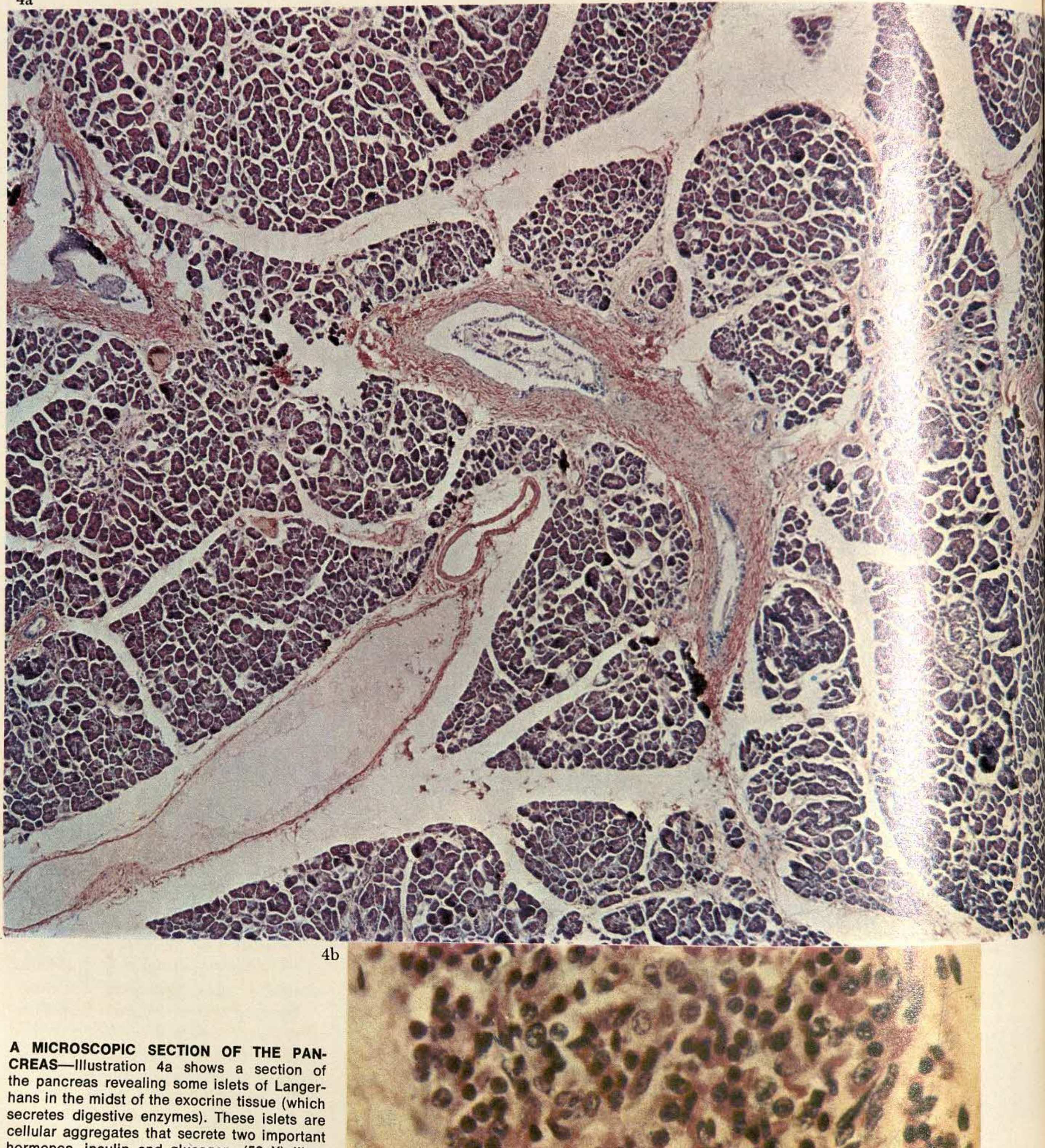
Insulin is a protein made up of 51 amino acids (all of which have been identified) arranged in two chains, one of 30 units and the other of 21 units. The chains are linked by two disulfide bonds between certain amino acids (cysteine) in the chains. Scientists succeeded in producing insulin artificially in 1966.

Insulin regulates the level of sugar (glucose) in the blood and keeps it at its normal concentration of 0.1 percent in the plasma. According to some, if there is an excess of glucose in the blood, insulin brings its concentration down to normal by accelerating the rate of its oxidation. According to others, insulin increases cellular permeability so that, if an excess of glucose occurs in the blood, the cellular membranes permit more glucose to enter the cells. Removal or destruction of the beta cells of the islets of Langerhans, which are the source of insulin, causes pancreatic diabetes.

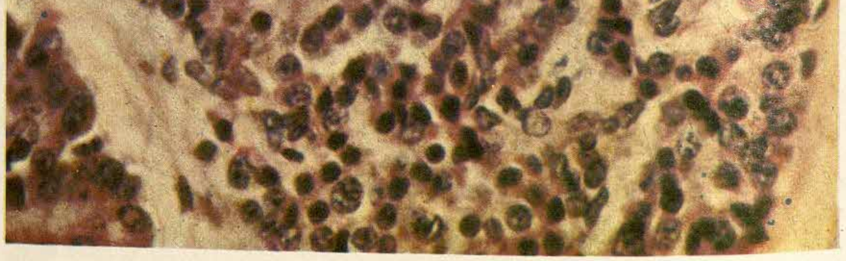
Glucagon acts in a manner antagonistic to that of insulin. Glucagon is a hyperglycemic factor: it inhibits the passage of glucose from the plasma into cells and causes the breakdown of glycogen to glucose, which then enters the plasma, thus increasing the blood sugar level.

The opposite activities of insulin and glucagon apparently permit the organism to maintain blood sugar at a constant level, thus providing a regular supply of fuel to the muscles, the principal motor organs.

4a



4b



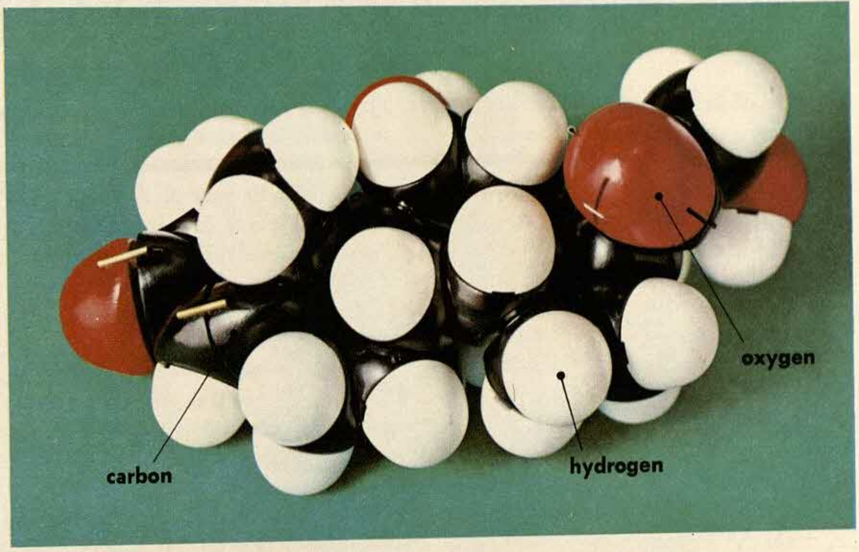
A MICROSCOPIC SECTION OF THE PANCREAS—Illustration 4a shows a section of the pancreas revealing some islets of Langerhans in the midst of the exocrine tissue (which secretes digestive enzymes). These islets are cellular aggregates that secrete two important hormones, insulin and glucagon. (50 X) Illustration 4b shows a section of an islet of Langerhans (300 X).

OTHER ENDOCRINE GLANDS

The gonads, or sex glands, are also numbered among the endocrine glands, for they produce the sex hormones. The male gonads, or testes, produce testosterone, which is secreted by the interstitial cells (Leydig cells). In the female gonads, or ovaries, the corpora lutea produce progesterone, and the follicular cells, which surround the ovum, secrete estrogen (folliculin). These various hormones regulate the development of the secondary sex characteristics; for example, testosterone stimulates the development of the crest that is characteristic of roosters but not of hens. Crests do not appear on capons (castrated chickens). Chemically, the sex hormones are sterols and so are similar to corticosterone and other hormones produced by the adrenal cortex.

The male hormone androgen stimulates the growth of muscle, skeleton, and viscera, accounting in part for greater musculature and stature in men than in women. The secretion of androgen is controlled by the pituitary interstitial cell-stimulating hormone. Androgen deficiency may be caused by a pituitary defect or by a primary interstitial cell failure. One result of the absence of androgen during adolescence is the delayed closure of the epiphyses, or ends, of the long bones. The consequence is disproportionately long arms and legs. A deficiency in estrogen, the female counterpart of androgen, is linked with atherosclerosis—the deposit of fatty materials in the walls of the arteries and arterioles. This condition increases the subject's vulnerability to circulatory diseases.

5a



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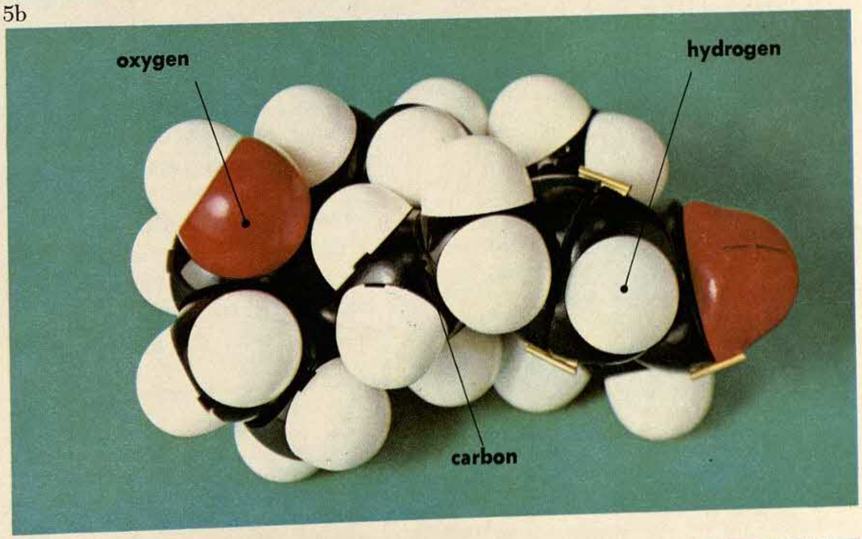
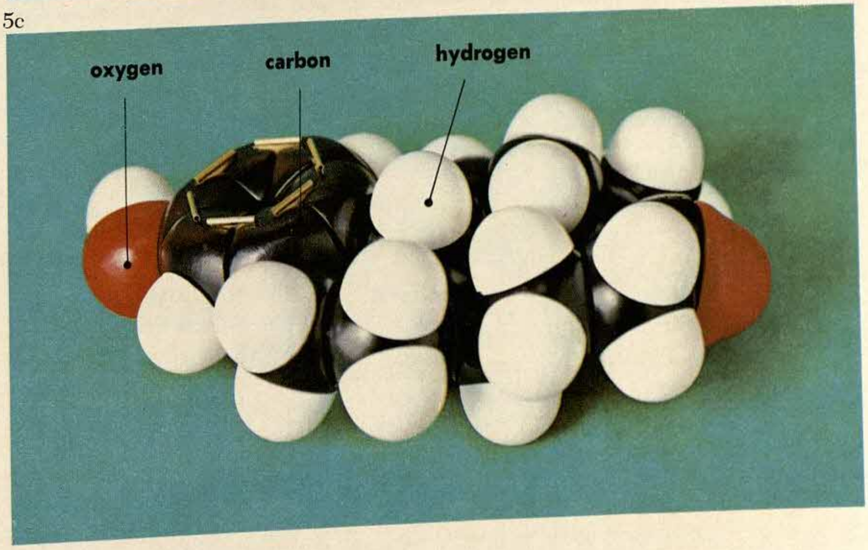


5c



HORMONE MODELS—Corticosterone (shown in Illustration 5a) is secreted by the adrenal cortex and regulates the metabolism of carbohydrates and proteins. Corticosterone also activates stored fats and diminishes muscle fatigue. Testosterone (Illustration 5b) is the principal male sex hormone and is secreted by the interstitial cells of the testes. Estrogen (Illustration 5c), also known as the follicular hormone, or estradiol, is secreted by the ovaries. Estrogen causes the development of female secondary sex characteristics; it stimulates the production of ACTH, the hormone of the hypophysis, and is largely responsible for growth and changes in the uterus during pregnancy.

THE RESPIRATORY SYSTEM | morphology and function

The task of supplying the body with the oxygen it must have is performed by the respiratory system. Its function is to absorb oxygen externally and transmit it to the bloodstream, which, in turn, distributes it to the tissues. At the same time, carbon dioxide, a waste product of metabolism, is removed from the body.

The respiratory system communicates with the environment by means of two apertures, the nose and the mouth. The nose opens externally by means of two nares or nostrils, and is supported by a bony framework and by a series of cartilages. A septum completely separates the two nasal cavities, and lateral cartilages help to support the outer walls of the nasal cavities.

Each nasal cavity is divided into a vestibule and the nasal cavity proper. The tissue that lines the vestibule is quite similar to the skin that covers the outer surface of the nose and is actually a continuation of it. It has sebaceous glands, sweat glands, and hairs called vibrissae. The function of the latter is to trap foreign particles in the air that enters the nose during inspiration.

The nasal cavity proper is lined with a mucous membrane; various types of cells are embedded in its epithelial layer. Some of the cells have an olfactory function, while others are pseudostratified, ciliated, epithelial cells; many of them are mucus-secreting cells.

Also communicating with the nasal cavities are a number of spaces, or air sinuses, in the bone. One of the functions of the sinuses is to trap inspired air, then warm it to body temperature before it passes to other parts of the respiratory system.

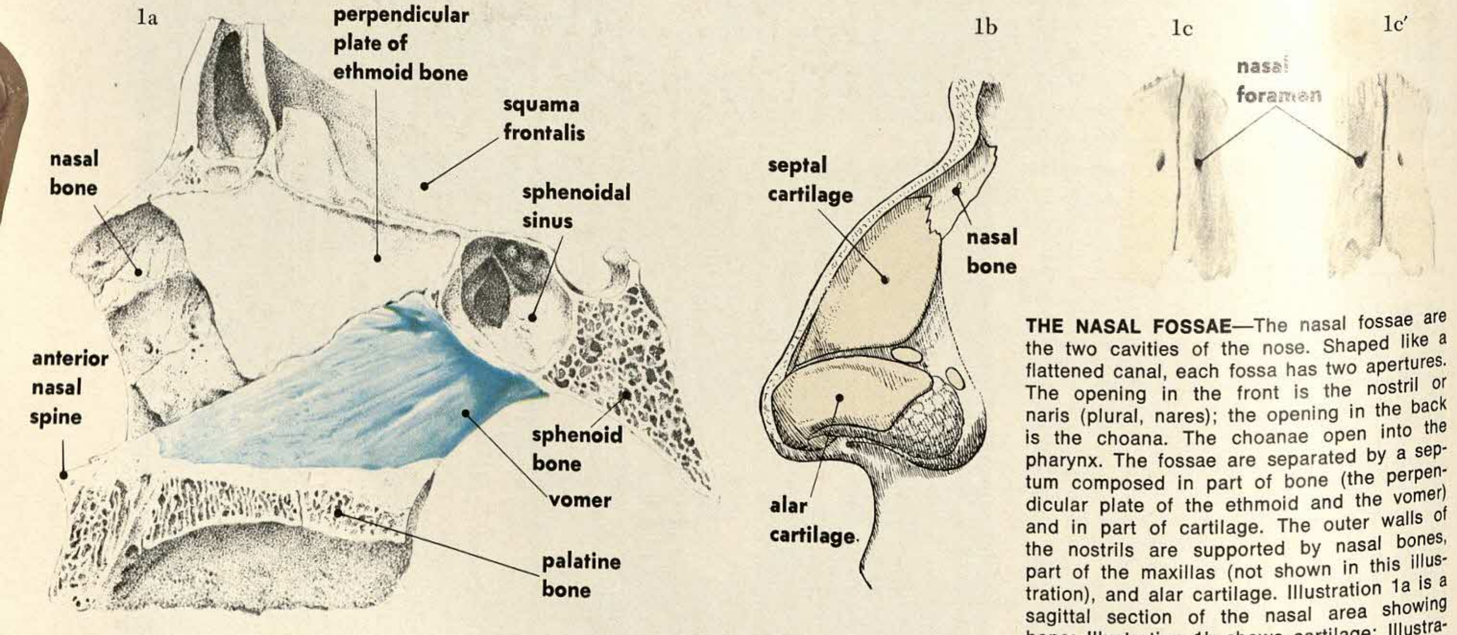
Air inhaled through the nose or the mouth passes into the pharynx, a chamber shared by both the respiratory and digestive systems. From the pharynx air moves to the larynx or voice box, a chamber located in the throat that is protected by a series of cartilages. One of them, the thyroid cartilage, is composed of two laminas that are fused together in an angle that forms the prominence in the throat that ancient anatomists called the Adam's apple (which is more marked in the male than in the female).

Stretched across the larynx are two ligaments, called the vocal cords, which produce sound as air passes through the larynx. The tension of the vocal cords, which is controlled by muscles, partially regulates the pitch of the voice. Women and children usually have short vocal cords that produce high pitch, whereas the longer vocal cords of men are responsible for their lower pitch.

Continuous with the larynx is the trachea or windpipe. Its framework consists of a longitudinal series of incomplete cartilaginous rings. Fibroelastic tissue covers the rings and extends between one ring and another. The lower extremity of the trachea bifurcates into two branches, the right and left bronchi, which extend to the lungs. The structure of the bronchi is quite similar to that of the trachea.

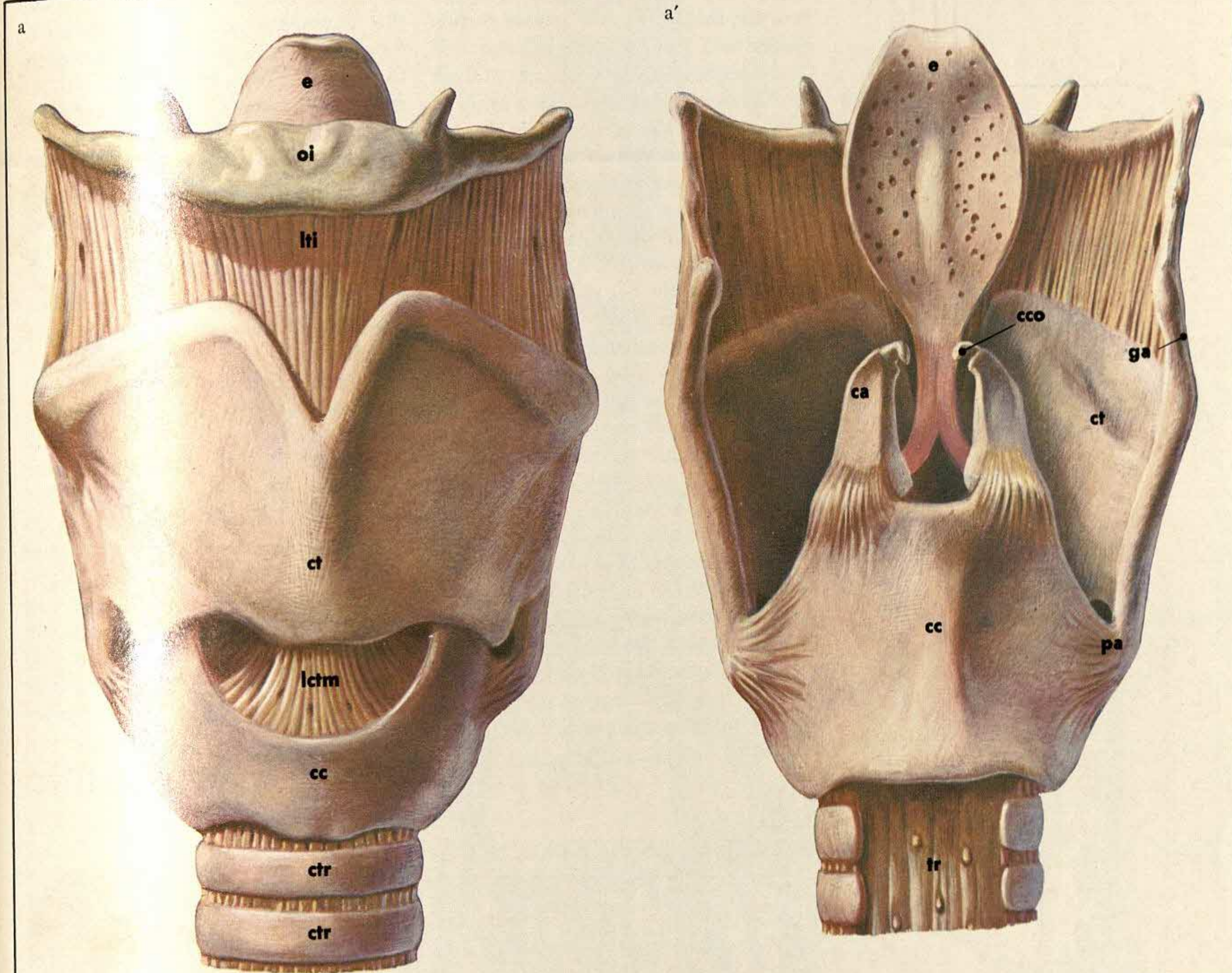
THE LUNGS

The lungs—located in the thorax or chest—are protected by the rib cage and are invested with a serous membrane, the pleura, which provides additional protection. The lungs of a newborn baby are



THE NASAL FOSSAE—The nasal fossae are the two cavities of the nose. Shaped like a flattened canal, each fossa has two apertures. The opening in the front is the nostril or naris (plural, nares); the opening in the back is the choana. The choanae open into the pharynx. The fossae are separated by a septum composed in part of bone (the perpendicular plate of the ethmoid and the vomer) and in part of cartilage. The outer walls of the nostrils are supported by nasal bones, part of the maxillas (not shown in this illustration), and alar cartilage. Illustration 1a is a sagittal section of the nasal area showing bone; Illustration 1b shows cartilage; Illustrations 1c and 1c′ are anterior and posterior views, respectively, of nasal bones.

2



THE LARYNX—The larynx is that part of the air passage that leads from the pharynx to the trachea. Illustrated above are the anterior (Illustration 2a) and posterior (Illustration 2a′) views of the larynx. The framework consists of cartilages, some of which are paired and some of which are unpaired and medial. The unpaired cartilages are the thyroid cartilage, the epiglottic cartilage, and the cricoid cartilage. The thyroid cartilage **ct** is composed of two laminas fused at an angle, forming a protective wall around the vocal folds which are essential for speech. The epiglottis **e** is elastic cartilage that is lowered over the glottis during the act of swallowing; this prevents food from entering the larynx. The cricoid cartilage **cc** is the cartilage on which the inferior cornua **pa** of the thyroid cartilage rest; it is connected to the thyroid cartilage by the middle cricothyroid ligament **lctm.** Also connected to the cricoid cartilage are the two arytenoid cartilages **ca,** which are extremely important in speech, for attached to them are the vocalis muscle and the vocal ligament. The corniculate cartilages **cco** are two small nodules located above the arytenoid cartilages. The hyoid bone **oi** is connected to the thyroid cartilage by the thyroid ligaments **lti,** which are inserted on the superior cornua **ga** of the thyroid cartilage. Below the larynx are cartilaginous rings **ctr** of the trachea **tr,** alternating with the interannular ligaments. Fibrous tissue (not shown) joins the end of the rings.

bright pink; later they become gray, and with advancing years they gradually become darker until they are almost black. This is caused by the accumulation of dust and other substances in the air that is inhaled. The lungs of city dwellers and smokers usually are darker than those of farmers and nonsmokers. The lungs are lobed, the right lung having three lobes, the left only two.

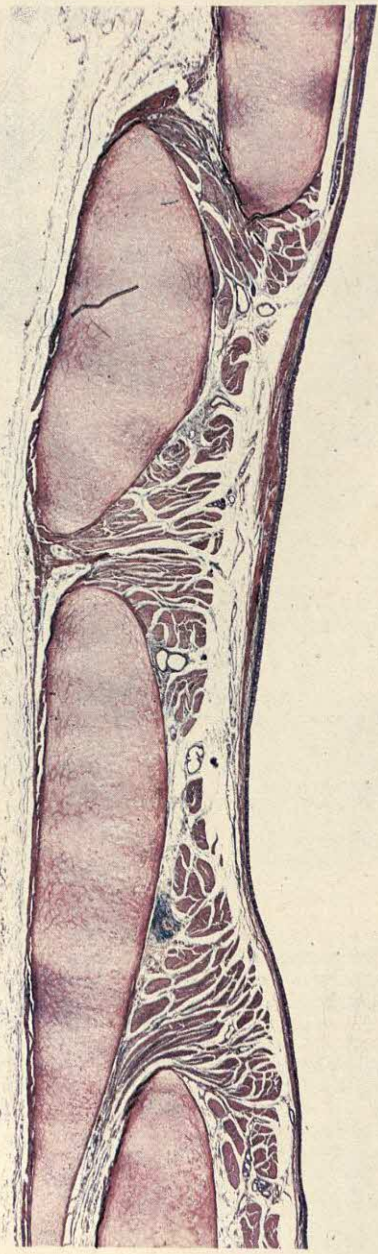
Once they have passed into the lungs, the bronchi branch into primary bronchi (one to each lobe of the lung), which in turn branch into secondary bronchi, then into tertiary bronchi, and so forth. The branches become progressively smaller; the smallest, called bronchioles, terminate in blind sacs, the alveoli. The walls of the alveoli contain blood capillaries that bring in blood that has traveled through other parts of the body. In the walls of the alveoli the red blood cells release oxygen to cells, which must have this gas to remain alive and perform their functions. Their activities produce a waste product—the gas carbon dioxide—which must be eliminated. The red blood cells absorb carbon dioxide from the tissues (such blood flowing toward the lungs is called spent blood). In the alveoli the red blood cells absorb oxygen from the inhaled air and release carbon dioxide to it. Then the air is exhaled, and the subsequent inhalation brings in fresh air. The oxygenated blood flows again to other parts of the body where the red blood cells again deliver oxygen and accept carbon dioxide.

The volume of the lungs varies from individual to individual, but the average volume of fully expanded lungs is about 6,500 cm^3 (about 6.8 qt) for an adult male. All of this is not exhaled at one time, however; the average volume of air exhaled in a very deep exhalation by an adult male is about 3,700 cm^3 (about 3.9 qt); this is known as vital capacity. At rest, the average man exhales about 500 cm^3 (about 0.5 qt) with each exhalation; this is called tidal air.

Breathing movements do not require voluntary thought, for breathing occurs automatically. (It is possible, however, to exercise conscious control over breathing.) Involved in the process are the activities of rib muscles and the diaphragm. The latter is a dome-shaped muscle that separates the thoracic cavity (chest cavity) from the abdominal cavity. When the diaphragm is relaxed, it bulges up into the thoracic cavity, which contains the lungs. At the same time, the rib muscles, which support the ribs, relax and allow the rib cage to descend slightly. Both of these reactions decrease the volume of the thoracic cavity and force air out of the lungs. When the diaphragm contracts, it moves downward; simultaneously, the rib muscles contract, raising the rib cage. This increases the volume of the thoracic cavity, and air moves into the lungs.

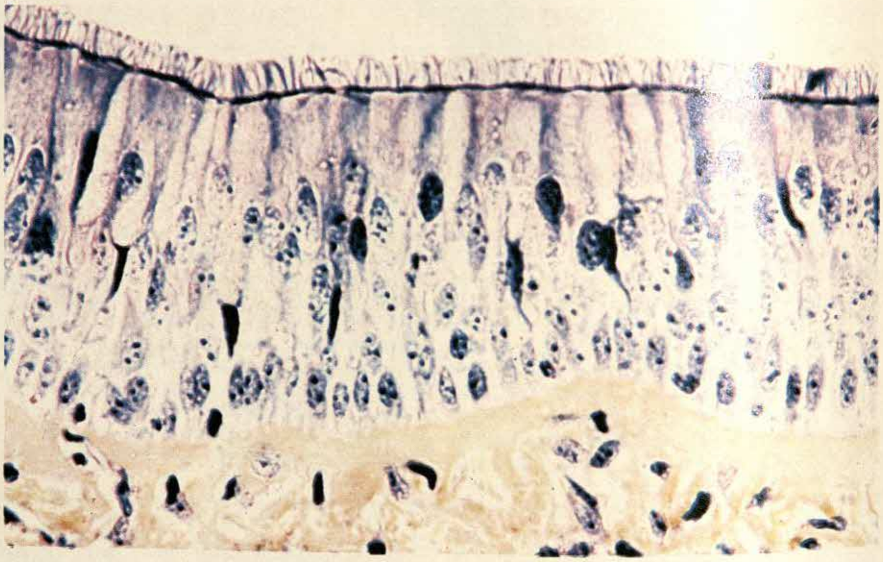
The relaxation and contraction of the respiratory muscles is controlled by nervous impulses coming from the medulla oblongata and pons of the brain. These, in turn, are affected by the carbon dioxide content of the blood. The higher the carbon dioxide concentration, the more rapid and deeper the breathing movements. Violent exercise is followed by deep breathing because exercise increases metabolic activities and thus increases the amount of carbon dioxide produced by cells and discharged into the bloodstream.

3



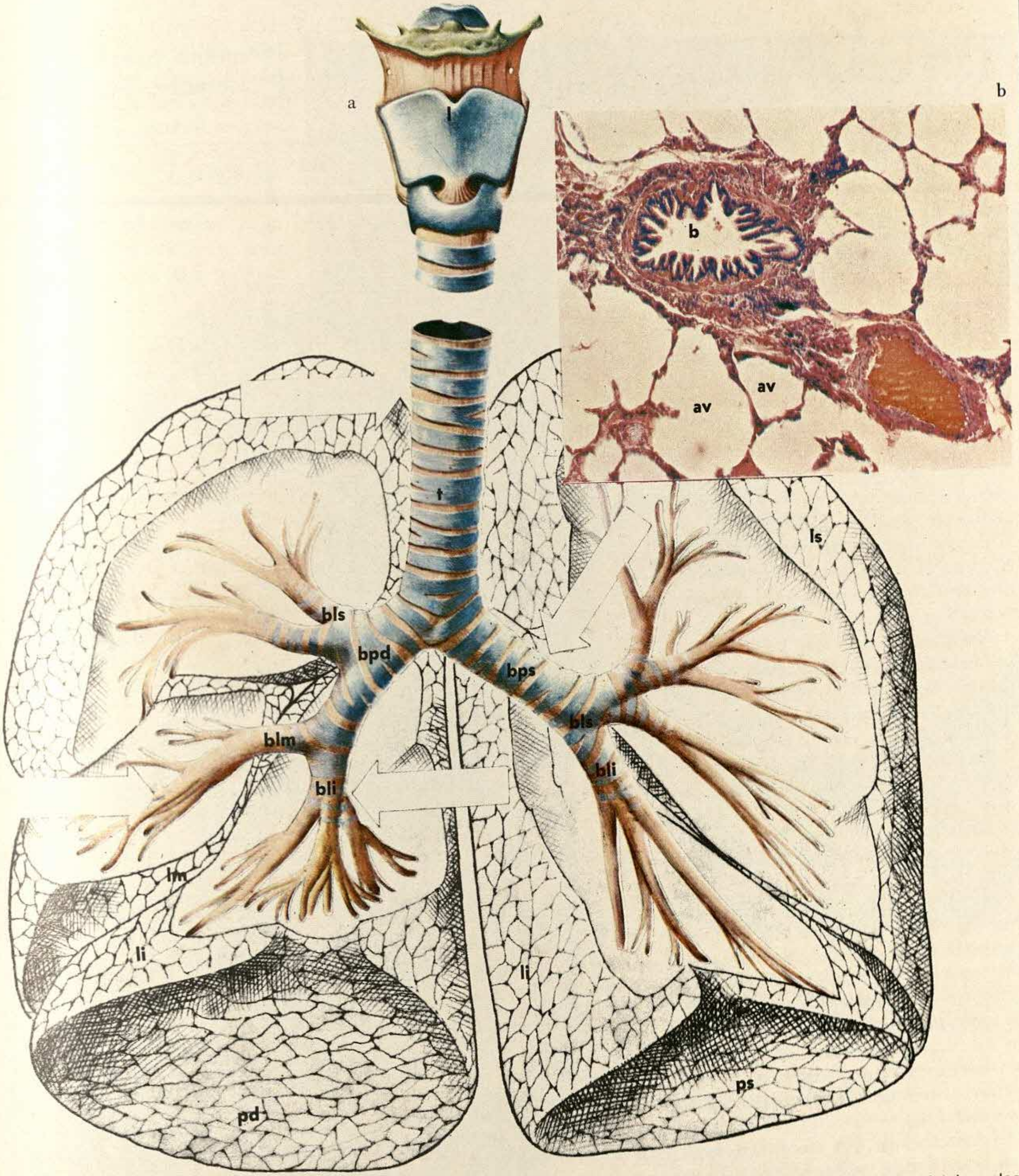
THE CARTILAGINOUS RINGS OF THE TRACHEA—This section of a human trachea was stained with hematoxylin and eosin and was photographed at low magnification. Sections of one tracheal ring and of parts of three others are visible.

4



EPITHELIUM OF A HUMAN TRACHEA—The numerous cilia lining the entire surface of the trachea are clearly visible in this greatly magnified section. The principal function of the cilia is to carry mucus and foreign substances contained in it toward the exterior. The cilia are present on the exterior surfaces of the epithelial cells. Among these cells are some secretory cells, called goblet cells, that can be recognized easily by their dark, slender bases that resemble the stems of goblets.

5



MORPHOLOGY OF THE RESPIRATORY SYSTEM—Some of the parts of the respiratory system are shown in Illustration 5a. The larynx **l** is supported by a cartilaginous framework which, in turn, is covered with a strong muscular tunica. The larynx communicates with the trachea **t**, which is surrounded by cartilaginous rings which are incomplete behind. The trachea branches into the right **bpd** and left **bps** bronchi (singular, bronchus), which penetrate respectively the right **pd** and left **ps** lungs, where they are further subdivided into smaller bronchi. The right lung has three lobes: the superior lobe **ls**, the middle lobe **lm**, and the inferior lobe **li**, into which the superior lobe bronchus **bls**, the middle lobe bronchus **blm**, and the inferior lobe bronchus **bli** enter. The left lung has only two lobes, the inferior lobe **li** and superior lobe **ls.** There are two corresponding bronchi, the inferior lobe bronchus **bli** and the superior lobe bronchus **bls.** The bronchi branch many times; the finest branches are microscopic. The final branches terminate in sacs called alveoli (not shown).

A magnified section of lung tissue stained with hematoxylin and eosin (Illustration 5b) shows a bronchiole surrounded by numerous alveoli; the extremely thin walls of the bronchiole are also lined with both columnar and cuboidal epithelium, which is ciliated in some areas. The exchange of gases between the air in the alveoli and the blood takes place by diffusion of these gases. The body's spent blood is low in oxygen, which it has distributed to the tissues, and high in carbon dioxide (CO_2), which it has absorbed from them. As it circulates in the capillary network of the alveoli, this blood is separated from alveolar air only by the extremely thin walls of the alveoli and blood capillaries. The alveolar air has a higher oxygen content and a lower carbon dioxide content than the red blood cells have. Therefore, oxygen diffuses from the alveolus to the red blood cells, and carbon dioxide from the blood cells to the alveolus. Continuous breathing renews fresh air in the alveoli. (53 X)

THE DIGESTIVE SYSTEM

mouth, esophagus, stomach, intestines

Human beings, like all other organisms, require a steady supply of energy. Unlike plants, which are able to utilize the energy present in sunlight, human beings and other animals must rely on food as an energy source. Starches, sugars, fats, fatty acids, proteins, and amino acids—these are the most important energy-containing substances in food. Some serve also as building blocks for the making of new cells as the body grows or repairs wounded tissues.

Not all of the substances contained in a meal can be absorbed by the body. Starches, fats, and proteins are large chemical compounds that must be digested to smaller ones—sugars, fatty acids, and amino acids, respectively. The function of the digestive system is the digestion of compounds and the absorption of the products of digestion.

The digestive tract may be thought of as a long tube open at both ends. Parts of the tube are wider than others, and some parts are folded back on each other. The digestive system can be divided into seven parts: the mouth, the pharynx, the esophagus, the stomach, the small intestine, the large intestine, and the rectum. In addition, the liver, gall bladder, and pancreas secrete materials into the small intestine.

Digestion begins in the mouth, where the teeth chew and grind the food, reducing it to small pieces. Not only does this make food easier to swallow, but it mixes the food with saliva and increases its surface area. The saliva, in addition to lubricating the food, also contains amylase, a starch-digesting enzyme. The tongue manipulates the food and assists in swallowing.

Human beings are omnivorous and consume a wide variety of food. Their diets require both biting and grinding of food. The flat, spadelike incisors and the canines, which are pointed in some humans, are well adapted to biting. The flat premolars and molars near the back of the mouth are good for grinding. Three main pairs of salivary glands secrete saliva into the mouth. The parotid

THE ORAL CAVITY—The mouth of an adult has 32 teeth, 16 in the upper jaw and 16 in the lower. Taste buds are located in papillae that cover the surface of the tongue, especially the large circumvallate papillae that lie near the back of the tongue. In the front are numerous small filiform papillae.

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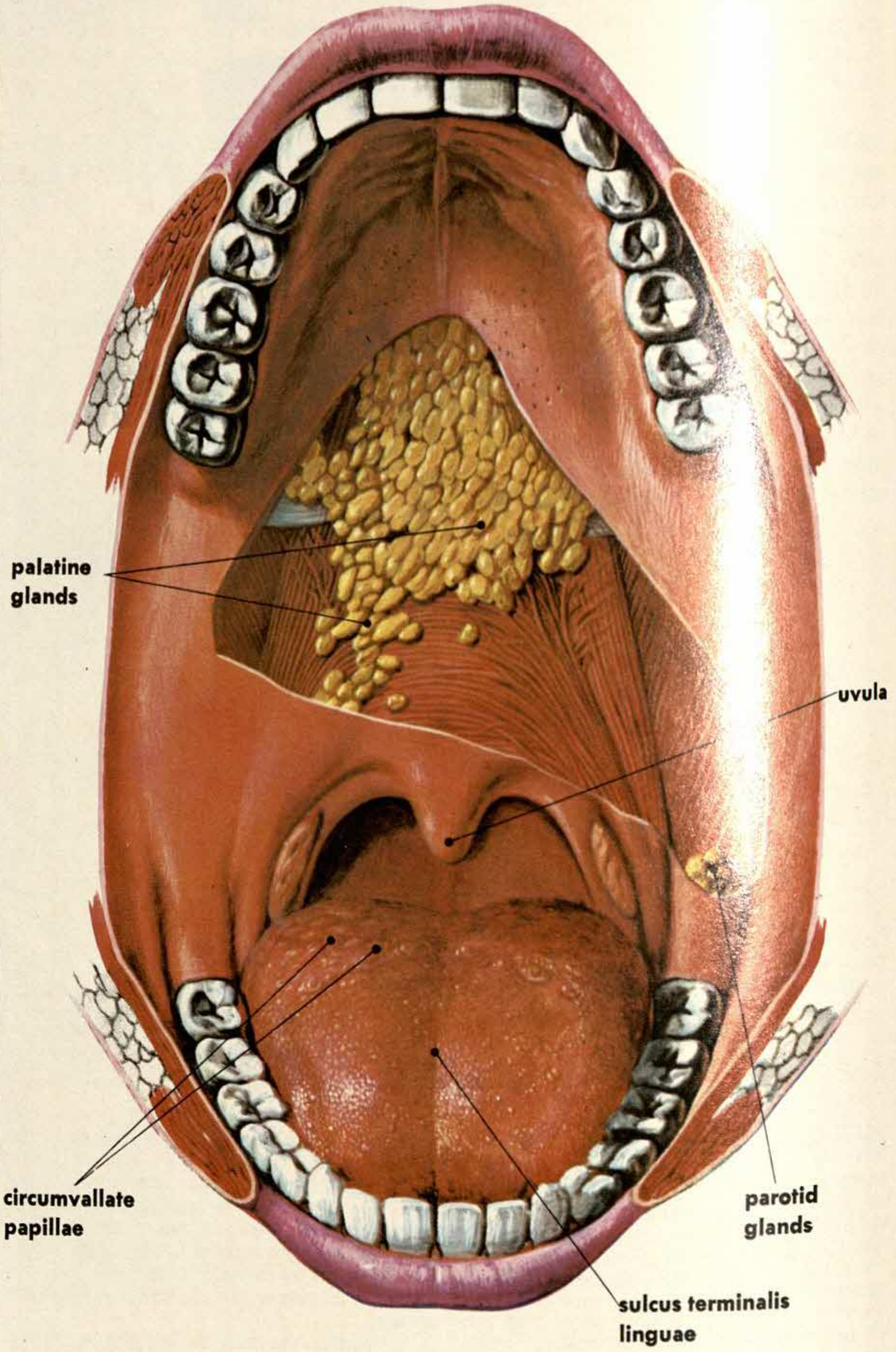


glands are in the cheek, and the submaxillary and sublingual glands are in the lower jaw. Lesser salivary glands are located in the palate, lips, and tongue.

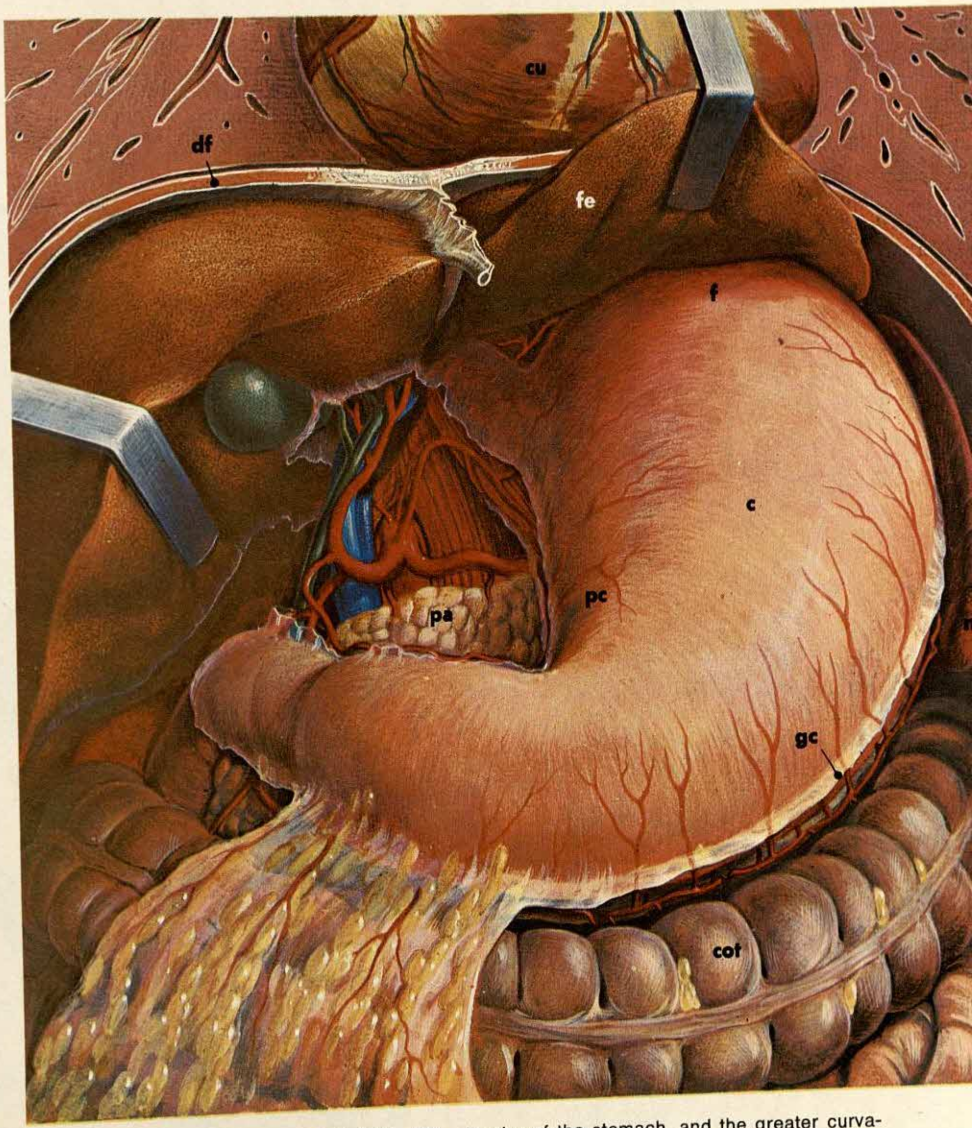
The upper surface of the tongue is covered with papillae that contain taste buds. The taste buds near the tip of the tongue are most sensitive to sweet and salty substances, the sides to sour and salty substances, and the back to bitter substances.

The mouth opens into the pharynx, a chamber shared with the respiratory system. The pharynx communicates with both the esophagus of the digestive system and the larynx of the respiratory system. The opening from the pharynx to the esophagus is ordinarily closed, allowing the individual to breathe freely. When food is swallowed, however, the larynx is closed; this allows food to enter the esophagus and prevents choking. The epiglottis, a flap of cartilage on the larynx, regulates the opening and closing of the esophagus and larynx.

The esophagus is a tube, about 22 to 25 cm (about 9 to 10 in.) long, located between the trachea in the front and the spinal column in the back. Food is forced downward in the esophagus by contraction waves of its muscular walls. Such contraction is called peristalsis. The lower part of the esophagus crosses in front of the aorta. The esophagus then passes through the diaphragm, enters the abdominal cavity, and widens into the stomach. The shape of the stomach is affected by several factors, including the amount of food it contains and whether the person is standing or sitting. Usually it tends to resemble a pear-shaped sac with the wider end tilted upward. The passage between the esophagus and the stomach is the cardiac orifice; the narrow end of the stomach, the pylorus, opens through the pyloric orifice into the small intestine. The upper part of the stomach is the fundus; the area between the fundus and the pylorus is the body of the stomach. The left border of the body is the greater curvature and the right one the lesser curvature. The stomach is held in position by its connection with the esophagus and the duodenum as well as by some ligaments. The stomach is a highly muscular organ. Churning action of its walls continues to break food down into still smaller pieces. The stomach lining contains glands that secrete pepsin, a protein-digesting enzyme, and lipase, a fat-digesting enzyme. The stomach contents are acid because hydrochloric acid is also secreted. Pepsin functions best in acid solutions. The stomach does not digest itself because the inner surface of the wall is protected by a lining of mucus.

Food moves from the stomach to the small intestine, the longest section of the tract. In an adult the small intestine measures about 7 m (about 23 ft) long. Digestion continues here, and digested food is absorbed. The small intestine is divided into three parts: the duodenum, the jejunum and the ileum.

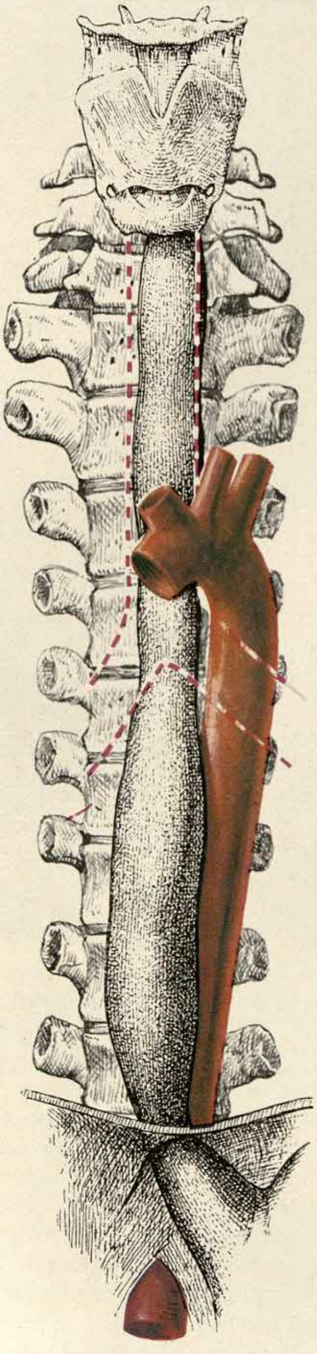
The duodenum is short, only about 25 cm (about 10 in.) long. Entering the duodenum is the common bile duct, which conducts bile from either the liver or the gall bladder to the duodenum. The



THE STOMACH AND ITS RELATION TO NEARBY ORGANS—To show the stomach in its entirety, the liver **fe**, which partly covers it, is raised. The main portion of the stomach is the body **c;** the wider upper portion is the fundus **f**. The lesser curvature **pc** is the right border of the stomach, and the greater curvature **gc** is the left border. The spleen **m** lies to the left of the stomach, and the pancreas **pa** lies behind it. The transverse colon **cot** is below. The diaphragm **df** separates these organs from the heart **cu.**

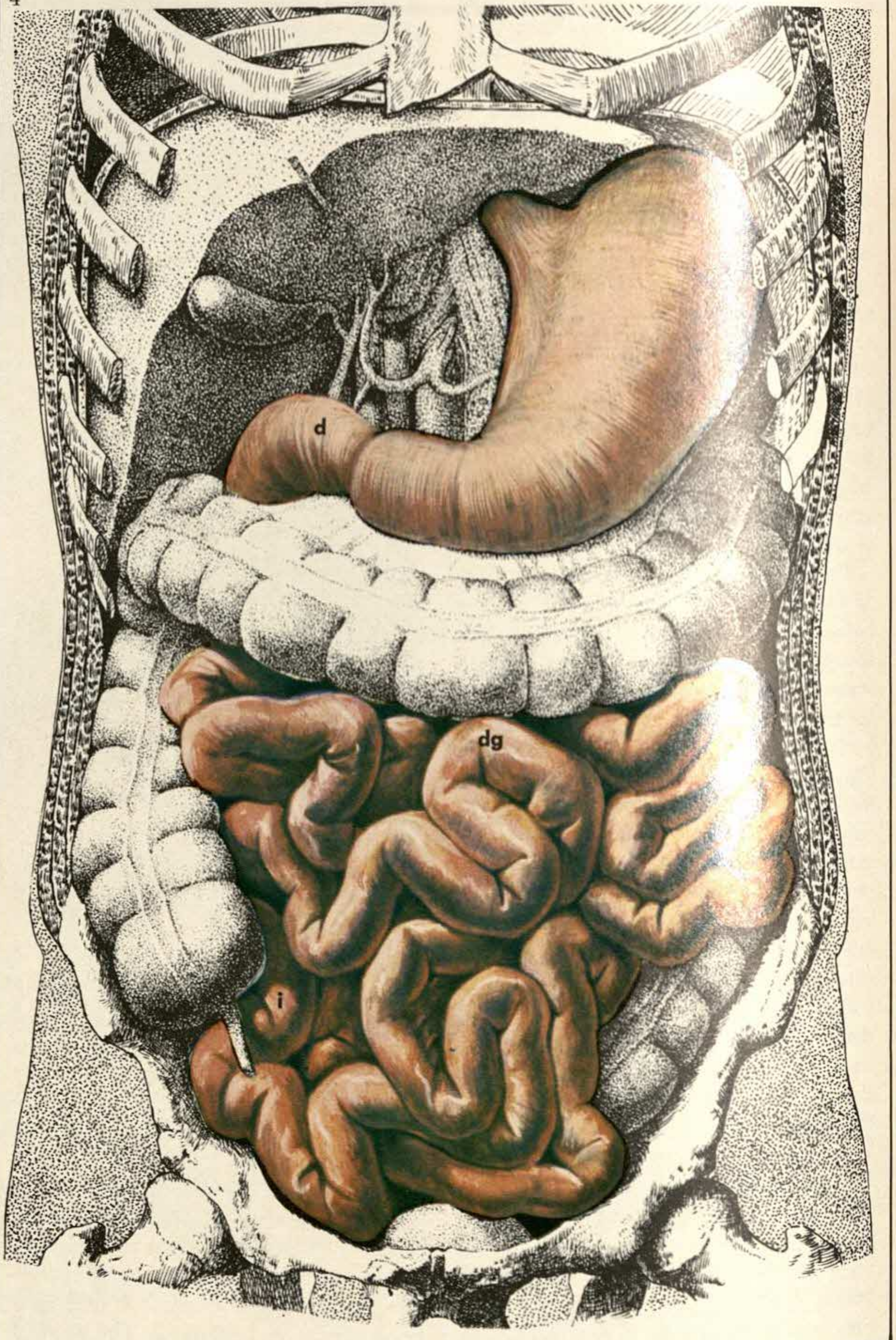
THE ESOPHAGUS—The esophagus (shown in gray) parallels the vertebral column, which lies dorsal to it. The trachea (dotted line) is ventral to it. The aorta (solid red) departs from the heart (not shown) in front of the aorta, and then crosses behind it.

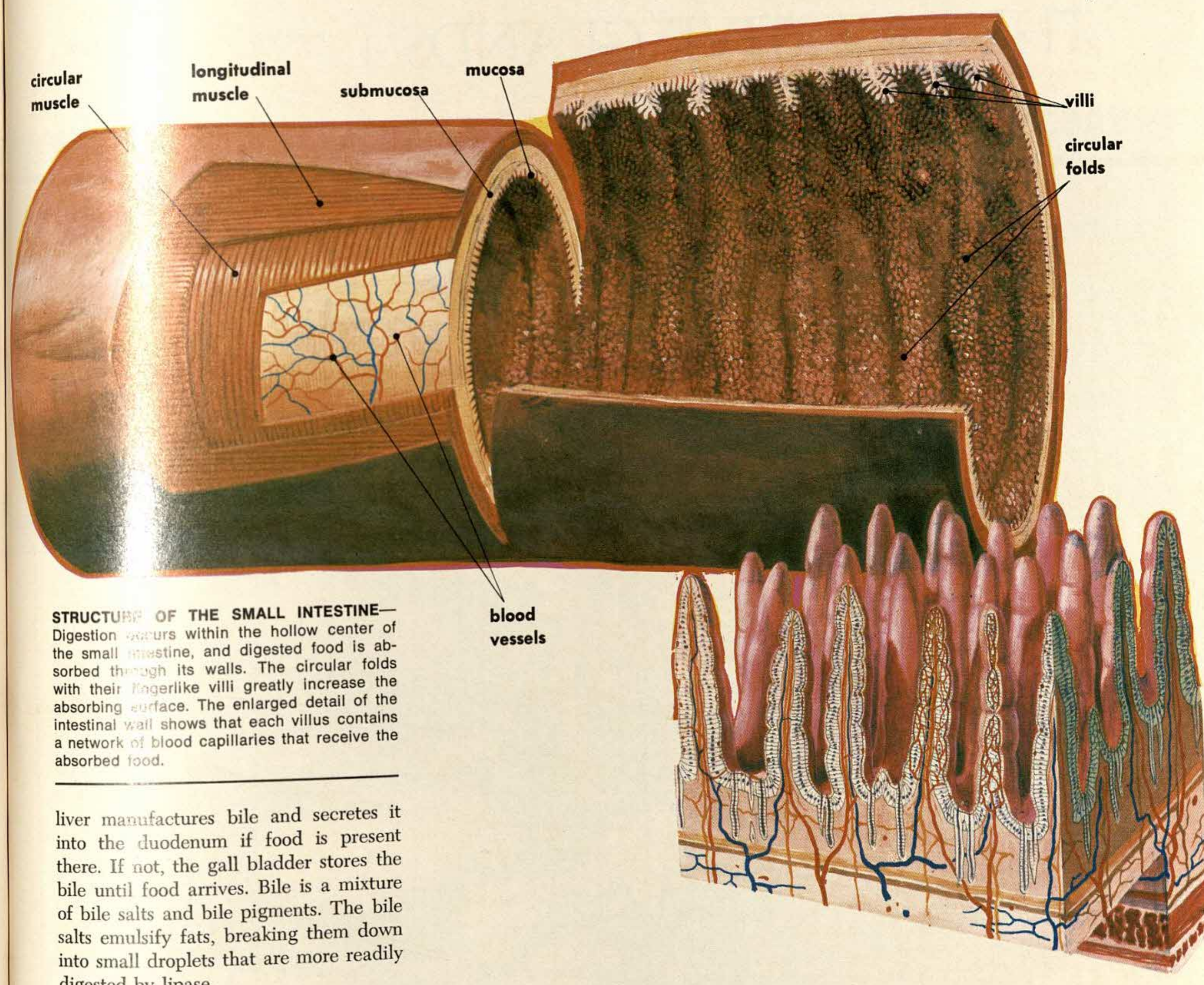
3



THE SMALL INTESTINE—The three parts of the small intestine are the duodenum **d,** jejunum **dg** and ileum **i.** The small intestine is so long that it can be accommodated only by folding over many times. Although the coils can be displaced, they are fixed to the posterior wall of the abdominal cavity by the dorsal mesentery, the supporting fold of the peritoneum. The large intestine is shown in white.

4





STRUCTURE OF THE SMALL INTESTINE— Digestion occurs within the hollow center of the small intestine, and digested food is absorbed through its walls. The circular folds with their fingerlike villi greatly increase the absorbing surface. The enlarged detail of the intestinal wall shows that each villus contains a network of blood capillaries that receive the absorbed food.

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liver manufactures bile and secretes it into the duodenum if food is present there. If not, the gall bladder stores the bile until food arrives. Bile is a mixture of bile salts and bile pigments. The bile salts emulsify fats, breaking them down into small droplets that are more readily digested by lipase.

The pancreas secretes more amylase, lipase, and several protein-digesting enzymes. The pancreatic juice is alkaline, and the enzymes it contains function best in an alkaline solution.

Food in the small intestine is subjected to peristalsis, which keeps it moving forward. Other muscular movements churn the food and mix it well with the enzymes. When digestion is complete, the intestinal contents have a watery consistency.

A second function of the small intestine is absorption of digested food; this occurs primarily in the ileum and jejunum, which comprise most of the small intestine. The inner surface of the wall of the small intestine contains circular folds that bear numerous fingerlike projections, the villi, which greatly increase the absorbing surface of the small intestine. Sugars and amino acids that enter the villi are carried away by the blood that circulates in them through fine capillary networks. Each villus also contains a lacteal, a fine extension of the lymph system that accepts fatty acids.

Whatever material is not absorbed in the small intestine passes into the large intestine, which is divided into three sections: the ascending colon, which turns upward on the right side of the body; the transverse colon, which passes across the abdomen from right to left; and the descending colon, which turns downward on the left side. Much of the water in the intestinal contents is absorbed by the large intestine. The undigested material thus is made drier and more nearly solid. This material, called feces, passes from the descending colon into the rectum.

The rectum is the terminal part of the digestive tract and communicates with the exterior through the anus. The opening and closing of the anus is controlled by a sphincter muscle.

THE DIGESTIVE GLANDS | making food absorbable

The human digestive tract is a long, twisted tube. Digestion occurs in the hollow of this tube rather than inside living cells. It is not surprising, therefore, that the digestive tract is well supplied with glands that secrete into it various digestive juices that aid in digestion. The contents of the secretions include enzymes that perform the actual chemical digestion; acid and alkaline compounds that regulate the pH in the several parts of the tract; and mucus, which lubricates the food and facilitates its passage along the tract.

The mouth is supplied with a variety of glands that secrete saliva. Some of the glands contain mucous cells, which secrete the slippery mucus; others contain

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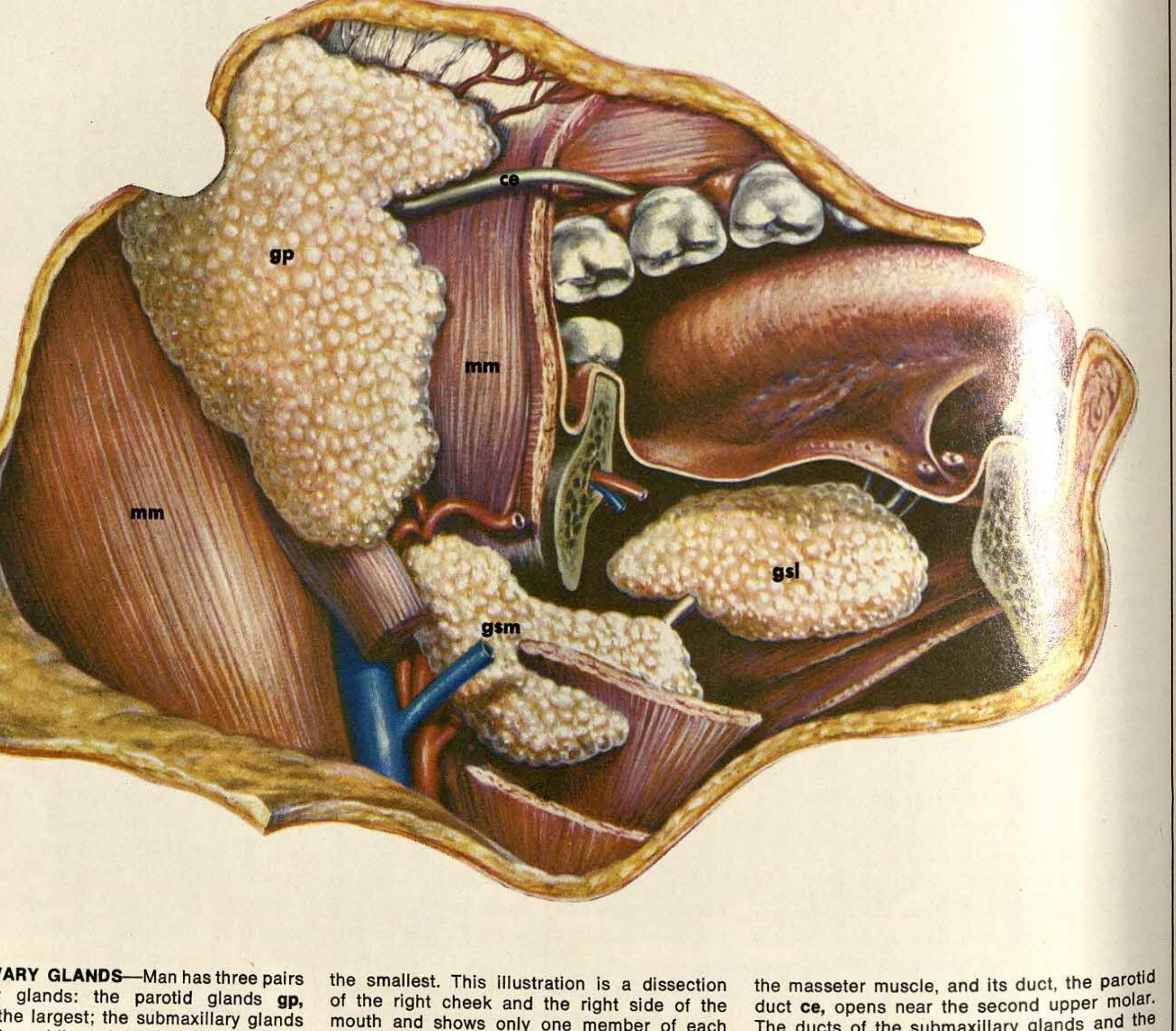
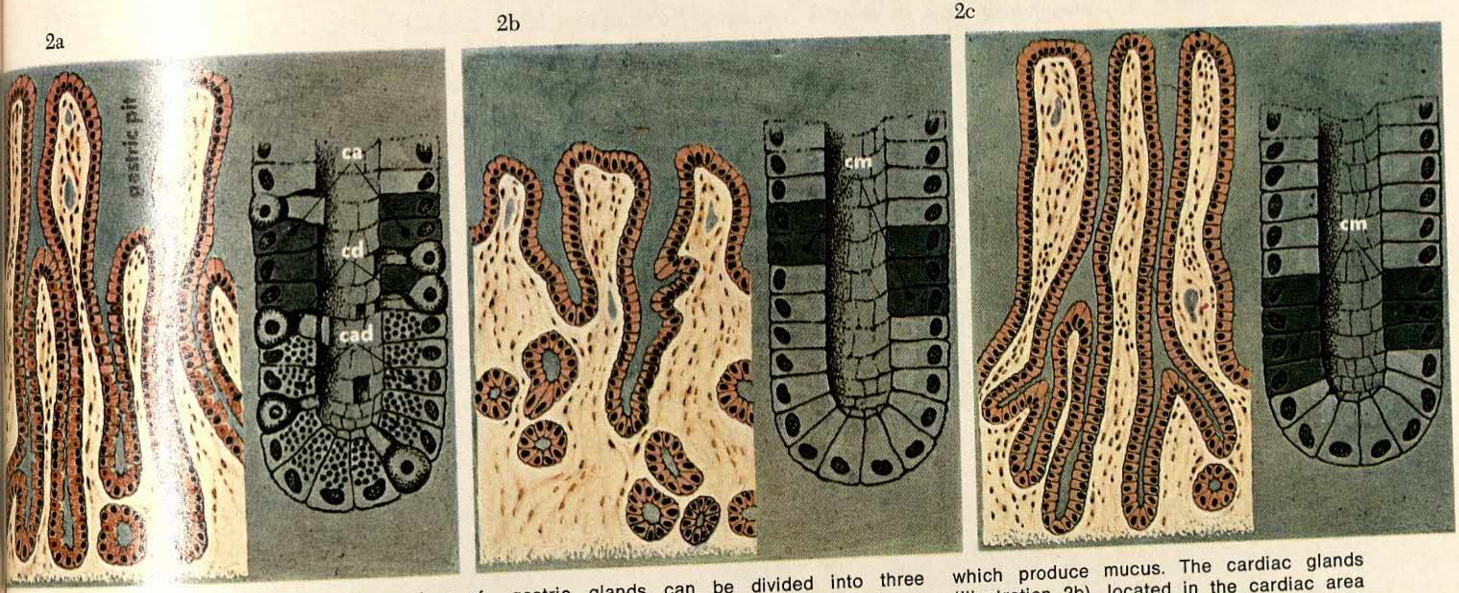


THE SALIVARY GLANDS—Man has three pairs of salivary glands: the parotid glands **gp,** which are the largest; the submaxillary glands **gsm;** and the sublingual glands **gsl,** which are the smallest. This illustration is a dissection of the right cheek and the right side of the mouth and shows only one member of each pair. The parotid gland is situated in a fold of the masseter muscle, and its duct, the parotid duct **ce,** opens near the second upper molar. The ducts of the submaxillary glands and the sublingual glands open below the tongue.



THREE TYPES OF GLANDS—The surface of the mucous membrane of the stomach is subdivided into minute areas called gastric areas. Each area has pits, called gastric pits, which are lined with simple columnar epithelium. Gastric glands open into the pits. According to their structure, position, and secretion, the gastric glands can be divided into three groups: fundic, cardiac, and pyloric glands.

The fundic or gastric glands (Illustration 2a) are simple tubulars composed of three types of cells: zymogenic cells **cad,** which secrete pepsinogen; parietal cells **cd,** which secrete hydrochloric acid; and mucous neck cells **ca,** which produce mucus. The cardiac glands (Illustration 2b), located in the cardiac area of the stomach, are branched tubular glands with mucus-secreting cells **cm.**

The pyloric glands (Illustration 2c) are also of the branched tubular type with mucus-secreting cells **cm.**

serous cells, which secrete a more watery fluid; and still others contain both types of cells. Mucus, the serous fluid, and ptyalin, a starch-digesting enzyme, comprise the saliva.

Three pairs of large glands are often considered the salivary glands proper. Of these, the parotid glands are the largest. These are serous glands, and they lie below and in front of the external ear. In the lower jaw are the submaxillary glands, which are almost entirely serous glands and have only a few mucous cells, and the sublingual glands, which are mixed glands. In addition to these, small labial glands and buccal glands are located in the cheeks; these are glands of mixed types. The lingual glands of the tongue are of both serous and mucous types, and the palatine glands of the roof of the mouth secrete mucus.

The esophagus, through which food travels to the stomach, also contains small mucous glands.

The stomach is also well supplied with glands. Its inner lining consists of tall columnar cells that secrete mucus. The inner surface is not smooth, however, but contains depressions, or gastric pits. Within these pits and secreting their products into them are the stomach or gastric glands. The most characteristic of the stomach glands are the fundic glands (sometimes also called gastric glands), which occur in the fundus and body of the stomach. The fundic glands contain mucous cells, zymogenic cells, which produce pepsinogen, and parietal cells, which produce hydrochloric acid. Pepsinogen is the precursor of pepsin, a protein-digesting enzyme that functions best in acid solutions. Other stomach glands are the cardiac glands and pyloric glands, which occur in the cardiac and pyloric portions of the stomach, respectively; both are mucous glands.

From the stomach food moves to the duodenum of the small intestine, which has its own glands and which receives contributions from both the liver and the pancreas. The inner surface of the small intestine is lined with fingerlike projections known as villi that absorb digested food and that also contain mucus-secreting cells. At the base of the villi are simple tubular glands called Lieberkühn's crypts; they produce digestive enzymes that are secreted into the lumen of the small intestine, where digestion occurs. Brunner's glands, which produce mucus and digestive enzymes, secrete their products into Lieberkühn's crypts, from which they proceed to the lumen of the intestine.

The liver, a large lobed organ lying in the upper part of the abdomen, is an organ of many functions. One of them is the production of bile salts, compounds that emulsify fats. Bile salts break large drops of fat into minute droplets, thus increasing the surface area on which fat-digesting enzymes can function. Bile (which includes bile salts and other products) is produced continuously by the liver. It moves to the gall bladder, where it is stored until food arrives in the duodenum. The bile then moves to the duodenum through the common bile duct, which has one branch from the gall bladder and another branch from the liver.

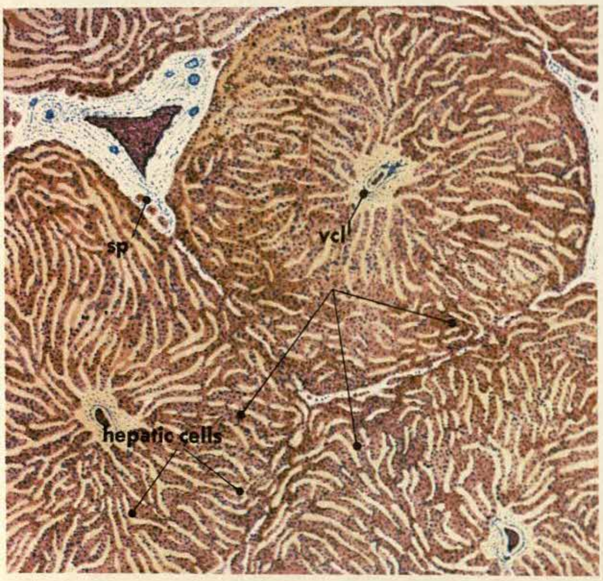
Other functions of the liver include the storage of glycogen and its conversion to glucose when this sugar is required, storage of vitamins A and B, formation of urea from ammonia and carbon dioxide, and detoxification of several toxic compounds that may be ingested.

The pancreas is another large gland of several functions. Its digestive function is the production of enzymes that are secreted into the duodenum through the pancreatic duct, which joins the common bile duct just before reaching the duodenum. The enzymes include amylase, which digests starch; lipase, which digests fats; and several protein-digesting enzymes. The pancreatic enzymes function best in alkaline solutions, and the pancreatic juice contains sodium bicarbonate, an alkaline compound that neutralizes the acid stomach contents arriving in the duodenum and makes them slightly alkaline.

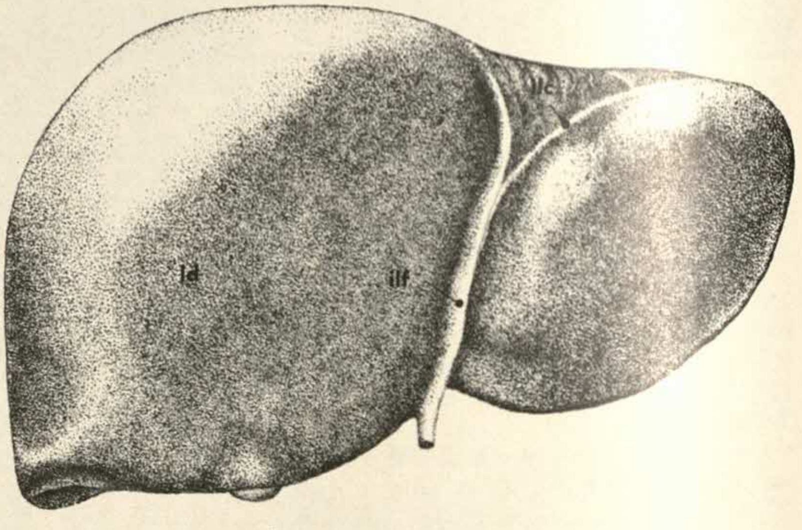
Certain clusters of pancreatic cells called islets of Langerhans have endocrine functions. They secrete directly into the bloodstream two hormones, insulin and glucagon, which regulate carbohydrate metabolism of the body.

Most of the digested food is absorbed by the small intestine; the material that reaches the large intestine is largely water and undigested material. The walls of the large intestine absorb much of the water, leaving the remaining material with a mostly solid consistency. The movement of this material is facilitated by secretion of mucus by Lieberkühn's crypts in the walls of the large intestine.

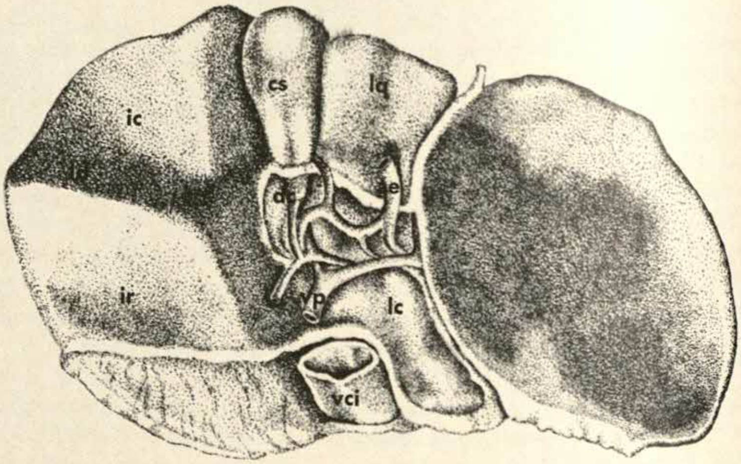
3a



3b



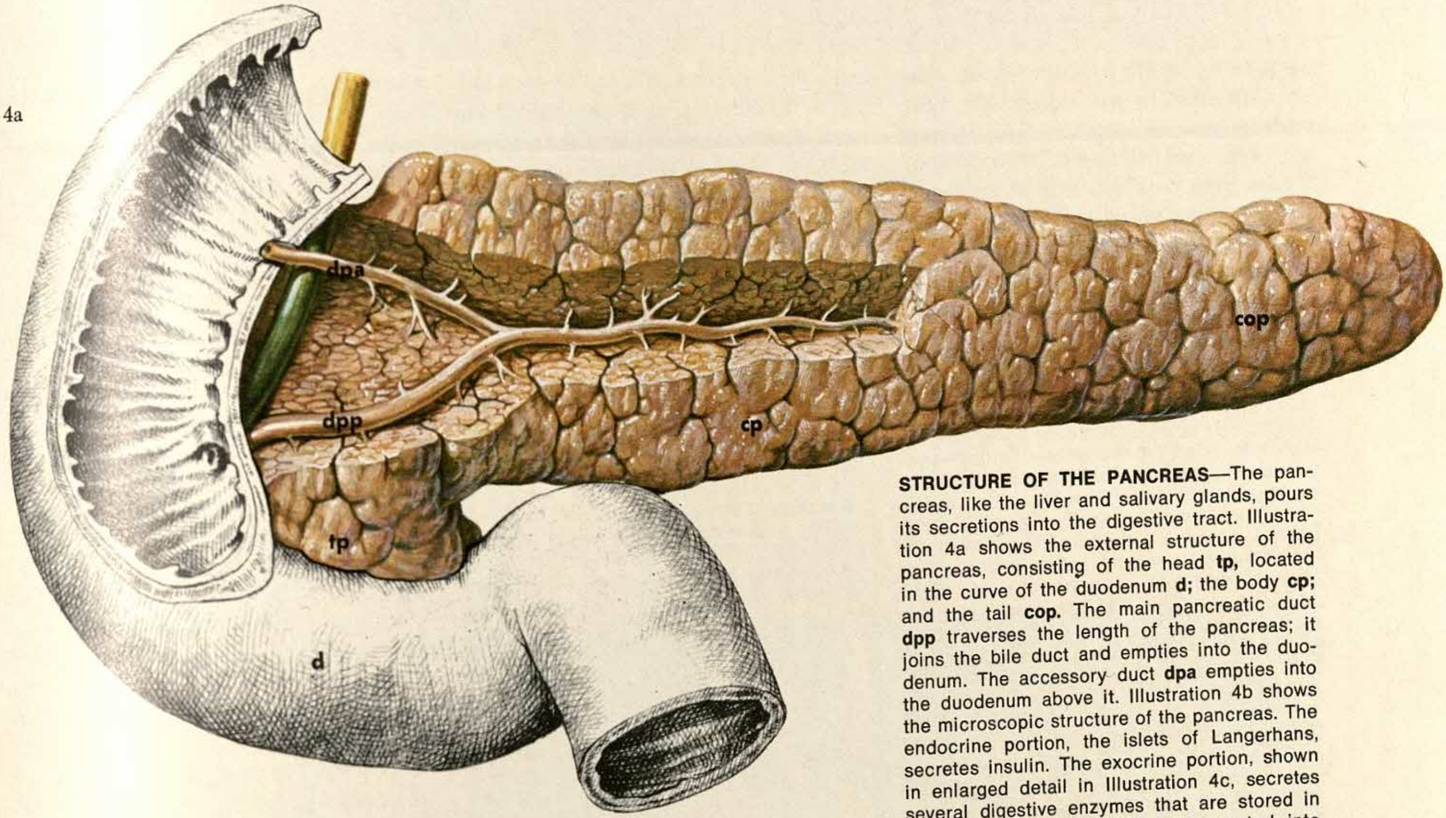
3c



STRUCTURE OF THE LIVER—Illustration 3a shows the microscopic appearance of the liver, which is divided into lobules **l.** Each lobule is composed of plates of cells that radiate from the central vein **vcl.** Among the lobules is connective tissue **sp** with arteries, veins, and bile ducts. Illustration 3b shows the ventral surface of the liver. The right lobe **ld** is larger than the left lobe **ls.** The falciform ligament **ilf** and the coronary ligament **ilc** connect the liver to other organs.

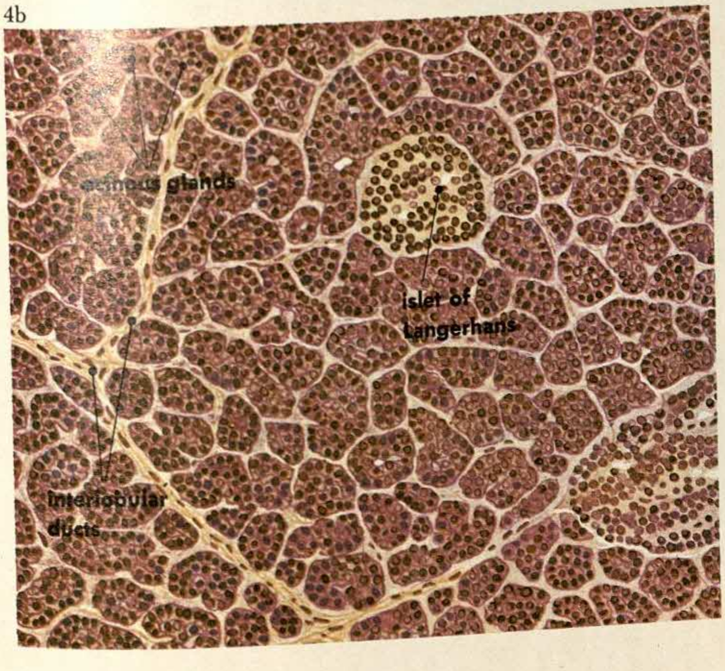
Illustration 3c shows the lower surface with four lobes: the right **ld,** left **ls,** quadrate **lq,** and caudate **lc** lobes. Impressions made by organs touching the liver are the gastric impression **ig,** the colic impression **ic,** and the kidney impression **ir.** Also visible are the gall bladder **cs,** cystic duct **dc,** inferior vena cava **vci,** hepatic artery **ae,** and portal vein **vp.**

4a

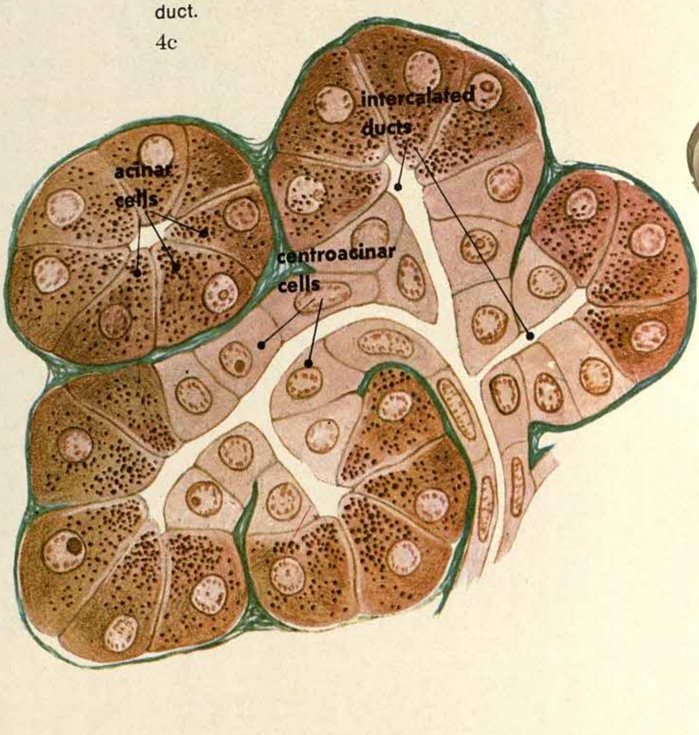


STRUCTURE OF THE PANCREAS—The pancreas, like the liver and salivary glands, pours its secretions into the digestive tract. Illustration 4a shows the external structure of the pancreas, consisting of the head **tp,** located in the curve of the duodenum **d;** the body **cp;** and the tail **cop.** The main pancreatic duct **dpp** traverses the length of the pancreas; it joins the bile duct and empties into the duodenum. The accessory duct **dpa** empties into the duodenum above it. Illustration 4b shows the microscopic structure of the pancreas. The endocrine portion, the islets of Langerhans, secretes insulin. The exocrine portion, shown in enlarged detail in Illustration 4c, secretes several digestive enzymes that are stored in zymogen granules. These are secreted into the intercalated ducts that lead to the interlobular ducts and eventually to the pancreatic duct.

4b



4c



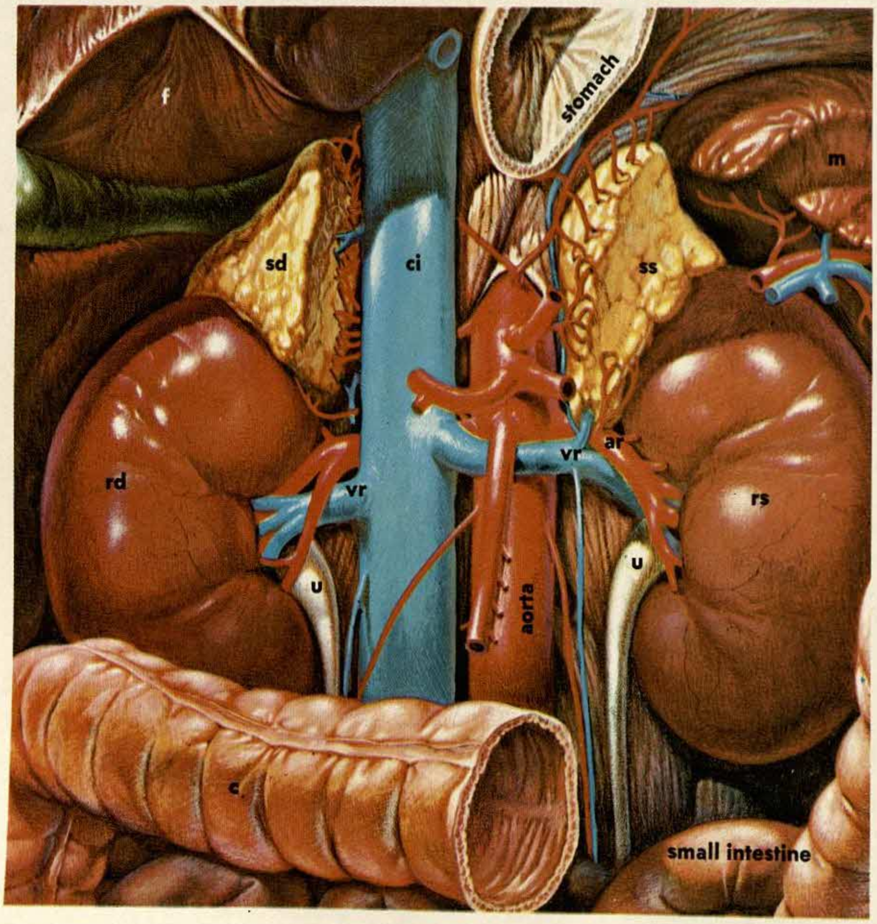
THE KIDNEY | the principal organ of excretion

Most of the waste products of the body are eliminated by the kidneys, the principal organs of excretion. The kidneys are two reddish-brown, bean-shaped organs lying on either side of the spinal column in the upper part of the abdominal cavity. They are covered by fibrous connective tissue and surrounded by fatty tissue. Additional connective tissue holds them in place. On top of each kidney is an adrenal gland, which produces a variety of hormones. The adrenal glands have no direct excretory function, but some of the hormones they produce affect the action of the kidneys.

The concave side of each kidney, the hilum, is oriented toward the midline of the body; the convex side is oriented away from it. The ureter, which drains urine from the kidney, departs from the hilum, and blood vessels and nerves enter here, too.

1

THE KIDNEYS—The two kidneys **rd** and **rs** lie on either side of the midline of the body. They occupy posterior positions in the abdominal cavity. They receive blood from the renal arteries **ar,** which are branches of the aorta, the main artery that proceeds from the heart. The kidneys remove wastes, especially urea, from the blood, which returns to the heart by way of the renal veins **vr** and the inferior vena cava **ci.** Urine, which consists of water, urea, and small quantities of other wastes, leaves the kidneys through the ureters **u,** which conduct it to the urinary bladder (not shown). Atop each kidney is an adrenal (suprarenal) gland **sd** and **ss.** These are endocrine glands that secrete a variety of hormones. The liver **f** and the spleen **m** have been raised to show the kidneys. Other abdominal organs visible in the illustration are the stomach, the large intestine **c,** and the small intestine.



INTERNAL STRUCTURE

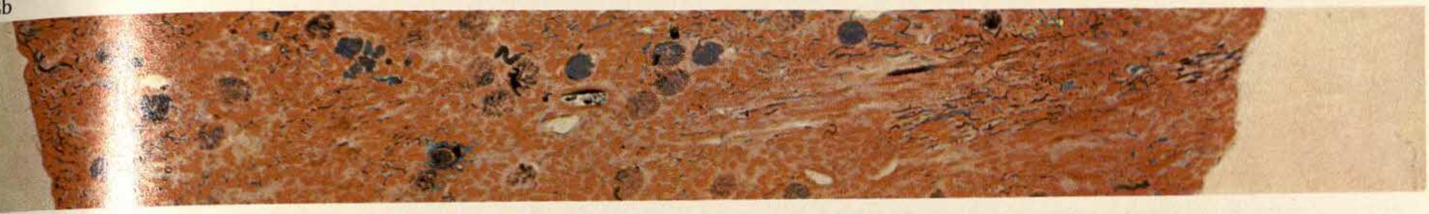
Two distinct zones can be seen when the kidney is cut open. The outer zone, the cortical substance, is yellowish-red in color while the inner zone, the medullary substance, is darker. The inner border of the medullary substance is uneven and consists of pyramid-shaped forms, with the apexes of the pyramids pointed toward the hilum of the kidney.

The functional units of the kidney are the nephrons, special tubes that collect waste materials and concentrate them. A human kidney has about one million nephrons. Each lies partly in the cortical substance and partly in the medullary substance.

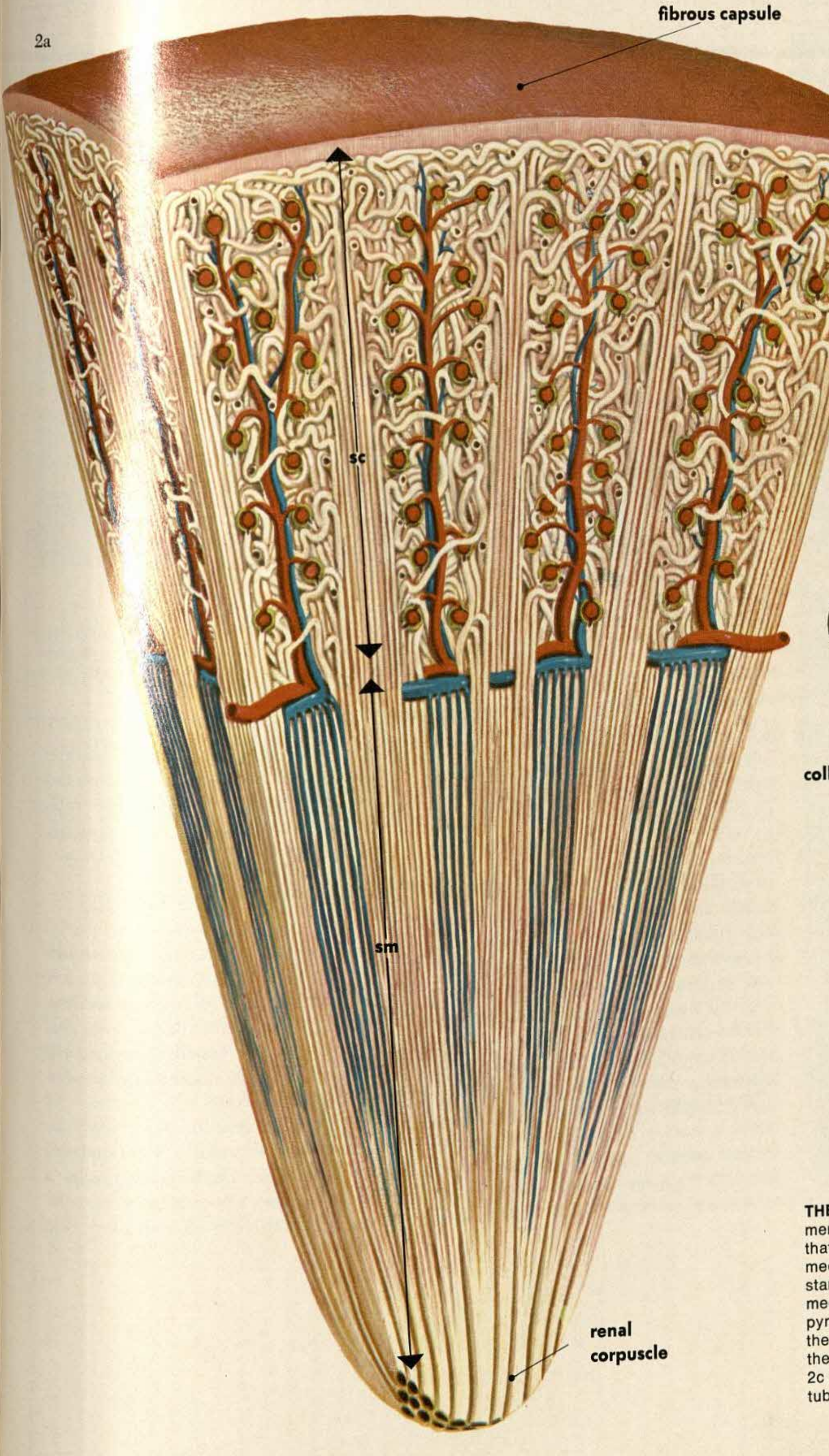
Metabolic waste (mostly urea) is transported to the nephrons by the blood. A renal artery enters the kidney at the hilum and branches into many minute arteries known as afferent arterioles. Each afferent arteriole branches further, forming a tuft of capillaries called a glomerulus. One end of each nephron is modified into a cup-shaped structure—called Bowman's capsule—that surrounds one glomerulus. The capsule and the glomerulus together are called a renal corpuscle, located in the cortical substance of each kidney. Bowman's capsule has a double wall, and the space between the two walls is continuous with the lumen of the rest of the nephron. The opening through which the arterioles enter Bowman's capsule is the vascular pole; through it an efferent arteriole, which collects blood from the glomerulus, leaves the capsule.

Because blood in the glomerulus is under pressure, some of its constituents are forced out of the capillaries and into the lumen of Bowman's capsule. Not only are wastes forced out, but a large

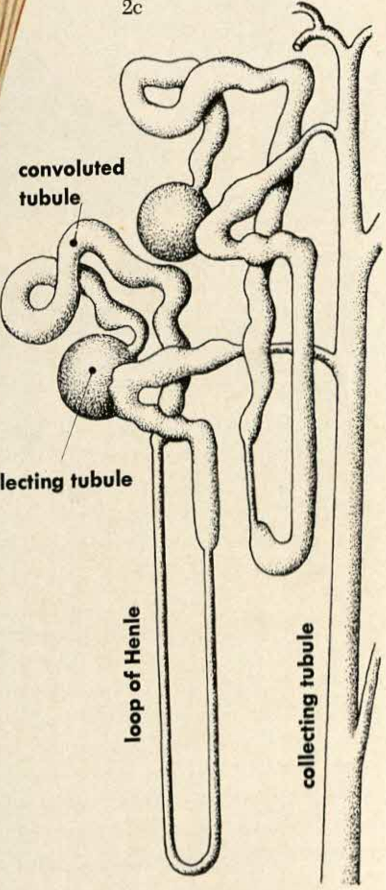
2b



2a

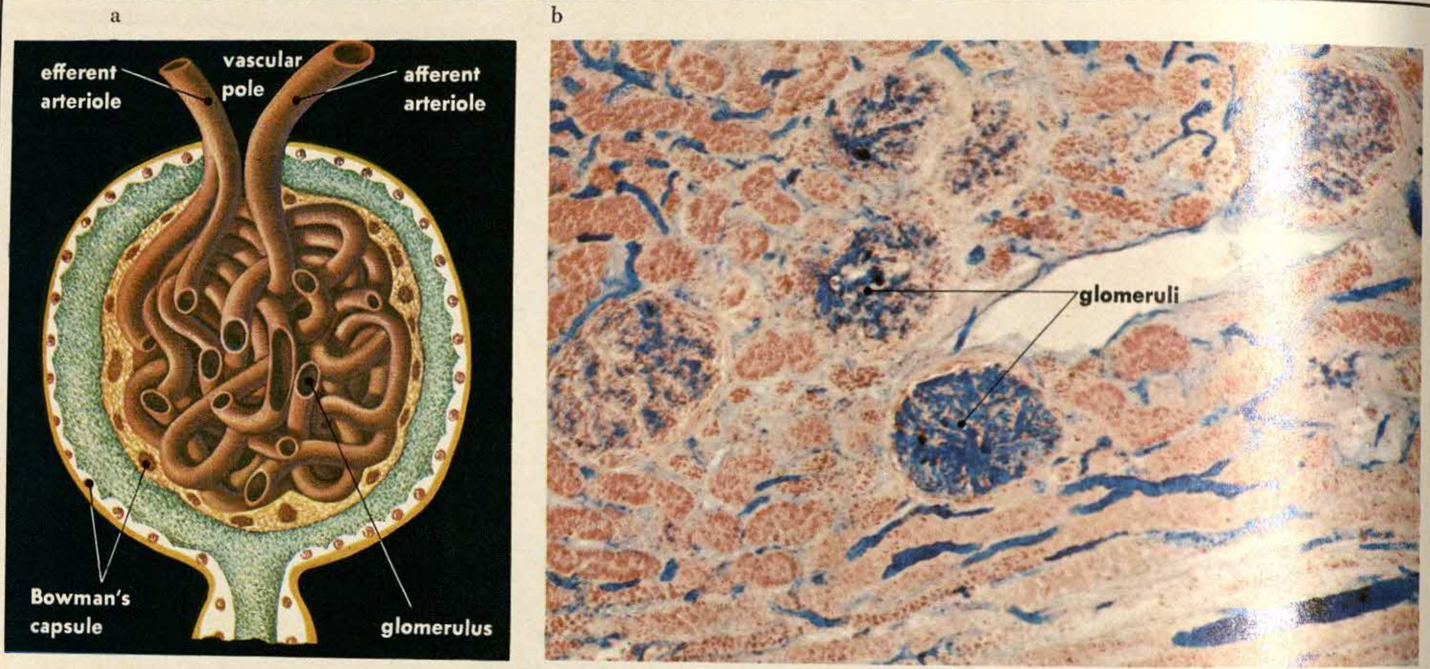


2c



THE STRUCTURE OF THE KIDNEY—This segment (Illustration 2a) is one lobe of the kidney that consists of cortical substance **sc** and medullary substance **sm.** The cortical substance is covered by a fibrous capsule. The medullary substance of each lobe is called a pyramid. A magnified and stained section of the cortical substance (Illustration 2b) shows the renal corpuscles (stained blue). Illustration 2c is a detail of the renal corpuscles and the tubules that remove wastes from the blood.

3



THE RENAL CORPUSCLE—Each renal corpuscle (Illustration 3a) consists of a double-walled structure, Bowman's capsule, that surrounds a network of blood capillaries, the glomerulus. Blood enters the glomerulus through an afferent arteriole, one of the minute branches of the renal artery. Blood leaves the glomerulus through an efferent arteriole, which leads to another set of capillaries that surround the convoluted tubules, a collecting tubule, and the loop of Henle.

Bowman's capsule, which is hollow, is continuous with the convoluted tubule. Illustration 3b is a stained section of cortical substance showing glomeruli. (105 X)

amount of water, glucose, and salts as well. The glomerular filtrate, as this solution is called, very much resembles the plasma of the blood, but it does not contain blood proteins of high molecular weight, and blood cells are not present in it.

The glomerular filtrate passes from Bowman's capsule into the rest of the tubule, which winds a twisted course. The portion near Bowman's capsule is the proximal convoluted tubule; it is much twisted, and lies within the cortical substance. It then narrows into a hairpin-shaped tube, the loop of Henle, which runs into the medullary substance and returns to the cortical substance. Here the tubule widens into the distal convoluted tubule. These three parts of the nephron are surrounded by a second net of capillaries that proceed from the efferent arteriole leaving Bowman's capsule. These capillaries collect water, glucose, and salts from the nephron, and so reduce the volume of the filtrate and concentrate the urea in it. The blood from these capillaries is collected by the renal vein, which returns it and the usable substances in it to the blood circulating through the rest of the body. Several nephrons empty their contents into a collecting tubule, and many collecting tubules traverse each pyramid of the medullary substance. Their final product is urine.

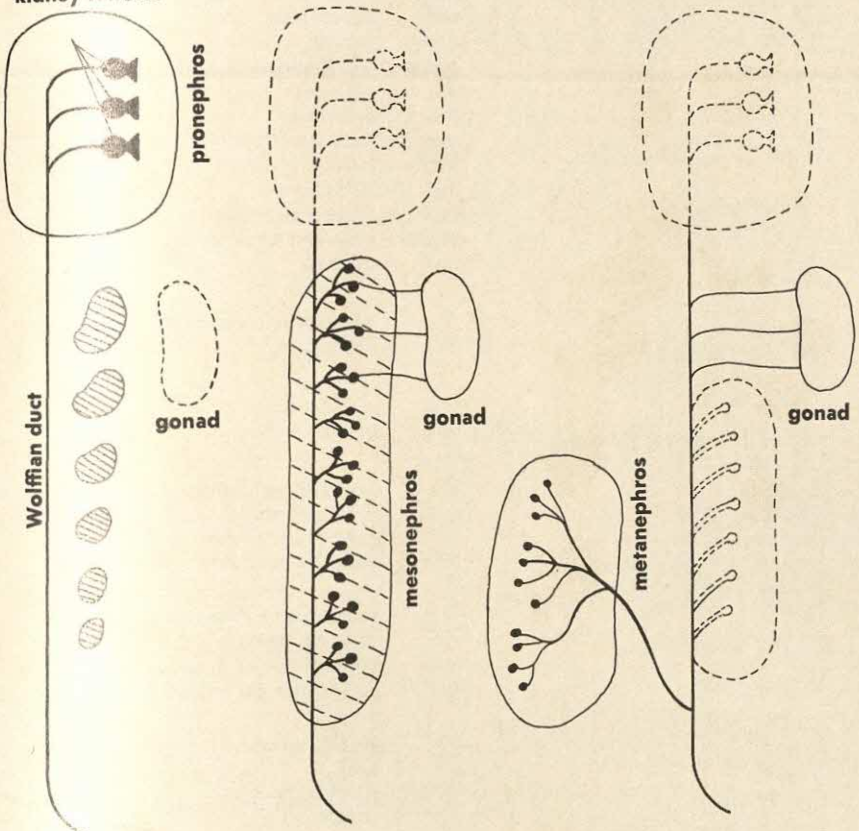
The nephrons function continuously; small quantities of urine leave the collecting tubules continuously and enter the ureters. Each kidney has one ureter, which by peristaltic contractions conducts the urine to the urinary bladder, where it is stored temporarily. Another duct, the urethra, conducts the urine from the bladder to the exterior of the body.

EVOLUTION OF THE KIDNEY

The most primitive animals have no kidneys. Single-celled animals either excrete their wastes through the cell membrane, or have special contractile vacuoles that collect wastes and conduct them to the surface of the cell, where they are discharged.

Somewhat larger animals, like the flatworms, have excretory ducts equipped with flame cells. These cells possess a tuft of cilia that direct wastes into the excretory ducts. The movement of the

4 **kidney tubules**



EVOLUTION OF THE KIDNEY SYSTEM—The pronephros is the most primitive kind of kidney. It is composed of a few kidney tubules that are open at one end and that empty into the Wolffian duct, which transports the wastes to the exterior. The pronephros is the adult kidney in only a few fish.

In most fishes and the amphibia, the pronephros is present in the embryo; however, it disintegrates and is replaced by the mesonephros, which consists of more complex tubules that also empty into the Wolffian duct.

As embryos, reptiles, birds, and mammals have both pronephros and mesonephros; the still more complex metanephros replaces them in the adult animal.

---

cilia gives the appearance of a flickering flame and is responsible for the name of the cell.

Each segment of an earthworm has a pair of excretory tubules, or nephridia. Each nephridium is open at both ends. It extends into the coelom, or body cavity, and has cilia that draw wastes into it. The other end leads to the exterior of the body.

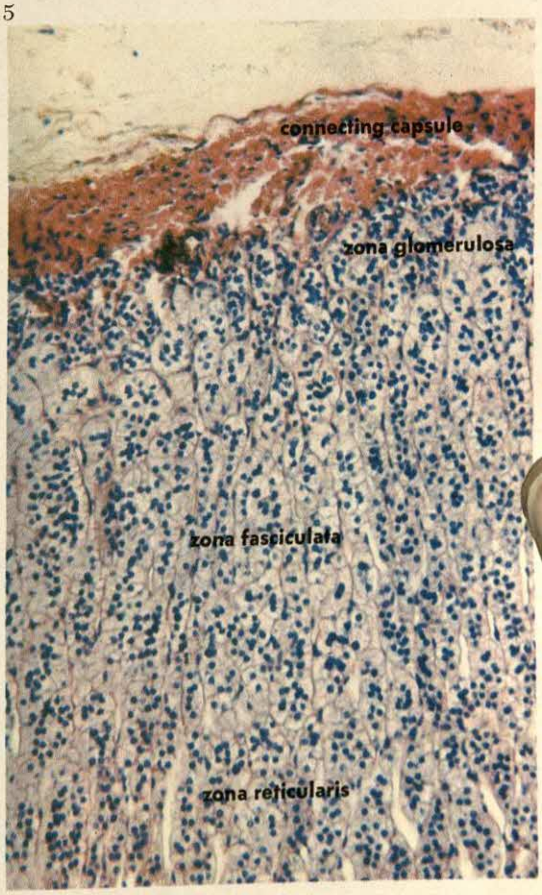
More advanced animals, like the vertebrates, have kidneys; but even within this group several different types of kidneys have evolved. The most primitive is the pronephros, which occurs in a few primitive fish. It consists of a few kidney tubules that resemble nephridia in having an open end in the body. Wastes are brought to the open ends of the tubules by glomeruli that lie near them. Rather than extending to the exterior of the body, the tubules all drain into a single tube, the Wolffian duct.

The mesonephros is a more advanced kidney characteristic of the adults of most fishes and amphibia. It contains some kidney tubules that resemble those of the pronephros and others that are equipped with Bowman's capsules. Both receive wastes from glomeruli.

The human kidney is a metanephros, which simply means the most highly evolved kidney. This type is found not only in mammals, but also in reptiles and birds.

THE ADRENAL GLANDS—This enlarged section of the cortex of an adrenal gland, one of which lies atop each kidney, shows it to have three zones. The zona glomerulosa produces the mineralocorticoid hormones that regulate the balance of water and salts in the body. The zona fasciculata produces glucocorticoid hormones (including cortisone) that regulate carbohydrate metabolism and affect connective tissues. Some sex hormones are believed to be produced in the zona reticularis.

5



ABBREVIATIONS

A	ampere
Å	Angstrom unit
abs	absolute
a-c	alternating current (as an adjective)
amu	atomic mass unit
atm	atmosphere
at. wt	atomic weight
AU	astronomical unit
avdp	avoirdupois
Bev	one billion electron volts
bhp	brake horsepower
bhp-hr	brake horsepower-hour
bp	boiling point
Btu	British thermal unit
C	temperature Celsius; temperature Centigrade
c	candle
cal	calorie
cfm	cubic feet per minute
cfs	cubic feet per second
cgs	centimeter-gram-second (system)
cl	centiliter
cm	centimeter
cm^2	square centimeter
cm^3	cubic centimeter
coef	coefficient
colog	cologarithm
cos	cosine
cot	cotangent
cp	candlepower
csc	cosecant
cu	cubic
cu ft	cubic foot
db	decibel
d-c	direct current (as an adjective)
doz	dozen
E	electromotive force
e	the base of the system of natural logarithms
ev	electron volt
F	temperature Fahrenheit
fp	freezing point
fpm	feet per minute
fps	feet per second
ft	foot; feet
ft^2	square foot
ft^3	cubic foot

ft-c	footcandle
ft-lb	foot-pound
G	universal gravitational constant
g	gram
gal	gallon
g-cal	gram-calorie
gpm	gallons per minute
gps	gallons per second
hr	hour
hν	photon energy
hp	horsepower
Hz	hertz (cycles per second)
I	electric current
ID	inside diameter
in.	inch
in.^{2}	square inch
in.^{3}	cubic inch
in.-lb	inch-pound
ips	inches per second
j	joule
K	temperature Kelvin (absolute)
kcal	kilocalorie
kg	kilogram
kg-cal	kilogram-calorie
kg-m	kilogram-meter
kg/m^3	kilograms per cubic meter
kgps	kilograms per second
km	kilometer
kv	kilovolt
kw	kilowatt
kwhr	kilowatt-hour
l	liter; lumen
lat	latitude
lb	pound
lb-ft	pound-foot
lb/ft^2	pounds per square foot
lb/ft^3	pounds per cubic foot
lb-in.	pound-inch
l-hr	lumen-hour
lin ft	linear foot
log	logarithm (common)
log$_e$	logarithm (natural)
long.	longitude
m	meter; minute (time, in astronomical circles)

m^2	square meter
m^3	cubic meter
ma	milliampere
Mev	one million electron volts
mg	milligram
mh	millihenry
mi	mile
mi^2	square mile
min	minute
m-kg	meter-kilogram
ml	milliliter
mm	millimeter
mm^2	square millimeter
mm^3	cubic millimeter
mμ	millimicron
mph	miles per hour
mphps	miles per hour per second
mv	millivolt
N	Avogadro's constant
n!	factorial *n*
OD	outside diameter
oz	ounce
pH	rating on acid-alkaline scale
ppm	parts per million
psi	pounds per square inch
psia	pounds per square inch absolute
R	temperature Reaumur; resistance
RA	right ascension
rpm	revolutions per minute
rps	revolutions per second
sec	secant; second
sin	sine
sp gr	specific gravity
sq	square
tan	tangent
V	volt
VA	volt-ampere
W	watt; work
yd	yard
yd^2	square yard
yd^3	cubic yard

SCIENTIFIC SYMBOLS AND ABBREVIATIONS

α	alpha particle
β; β^-	beta particle
β^+	positron
γ	gamma radiation
Δ	a small change; heat
λ	wavelength; radioactive-decay constant
ma	milliampere
μc	microcurie
μf	microfarad
μin.	microinch
μm	micron
$\mu\mu$	micromicron
$\mu\mu$f	micromicrofarad
ν	frequency; neutrino
π	3.14159; osmotic pressure

Σ	the sum of
σ	nuclear cross section (barns); area
Ω	electrical resistance (ohms)
ω	angular speed; angular velocity
$'$	minute (angular measure)
$''$	second (angular measure)
♂	male
♀	female
$>$	is greater than
$<$	is less than
$\propto$	is proportional to
∞	infinity
$\sqrt{\ }$	square root of
$^\circ$	degrees; temperature; angle measurement (example, 30°)

[ ]	molar concentration
$+$	positive electric charge; mixed with; plus
$-$	negative electric charge; single covalent bond; minus
$=$	equals; double covalent bond; produces
$\neq$	does not equal
$\equiv$	triple covalent bond
$\rightarrow$	produces; forms; chemical reaction
$\rightleftarrows$	reversible chemical reaction
$\uparrow$	gas produced by a chemical reaction
$\downarrow$	precipitate produced by a chemical reaction
*	radioactive substance (follows symbol of element; example, Cl*)

THE ILLUSTRATED SCIENCE DICTIONARY

Armature to Blowout

KEY TO PRONUNCIATION

The diacritical marks are:

ə	b*a*nan*a*, *a*but
ᵊ	preceding l, m, n as in batt*le*
ə̇	*e*lectric
ər	f*ur*ther
a	m*a*t
ā	d*ay*
ä	c*o*t, f*a*ther
aů	n*ow*, *ou*t
e	b*e*t
ē	b*ea*t
i	t*i*p
ī	b*i*te
j	*j*ob, *g*em
ŋ	si*ng*
ō	b*o*ne
ȯ	s*aw*, *a*ll
ȯi	c*oi*n
th	*th*in
t̲h̲	*th*en
ü	r*u*le, f*oo*l
u̇	p*u*ll, w*oo*d
ue	German h*ü*bsch
u̅e̅	French r*ue*
yü	*u*nion
zh	vi*si*on

ˈ mark preceding the syllable with strongest stress.

ˌ mark preceding a syllable with secondary stress.

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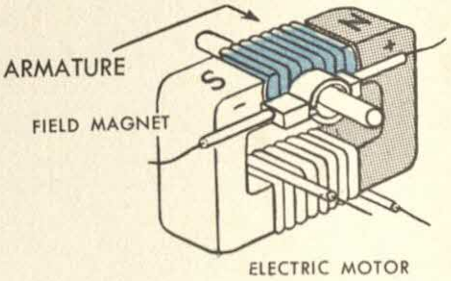
armature \'är-mə-ˌchu̇(ə)r\ *n.*
PHYSICS. A part of a dynamoelectric machine through which electrical energy is changed to mechanical energy (motor) or mechanical energy to electrical energy (generator).

An ARMATURE *usually has a core of soft iron or steel.*



arsenic \'ärs-nik\ *n.*
CHEMISTRY. A gray, brittle element with a metallic luster. Symbol, As; atomic number, 33; atomic weight, 74.92.

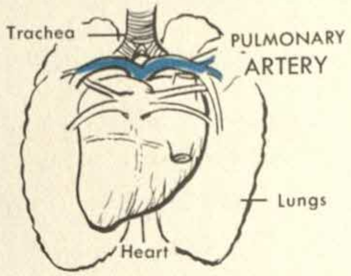
Some compounds of ARSENIC *are highly poisonous.*

arterioles \är-'tir-ē-ˌōlz\ *n.*
ANATOMY and ZOOLOGY. The small branches of the arteries that lead into the capillaries.

ARTERIOLES *and capillaries can be seen in the foot of a frog by using a microscope.*

arteriosclerosis \är-ˌtir-ē-ō-sklə-'rō-səs\ *n.*
MEDICINE. A disease characterized by the thickening and hardening of the body's arteries. It is most common in older persons.

In ARTERIOSCLEROSIS, *fatty deposits in the inner lining of arterial blood vessels cause a loss of elasticity and eventually impede the flow of blood.*



artery \'ärt-ə-rē\ *n.*
ANATOMY and ZOOLOGY. A blood vessel through which blood moves away from the heart and to the tissues.

The pulmonary ARTERY *carries blood from the heart to the capillaries in the lungs.*

artesian well \är-'tē-zhən 'wel\
EARTH SCIENCE. A deep well in which water is forced upward by internal pressure.

An ARTESIAN WELL *seldom runs dry.*

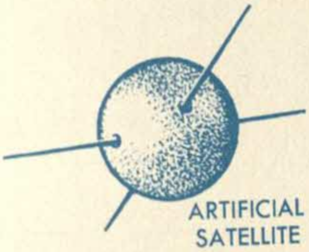
artifact \'ärt-ə-ˌfakt\ *n.*
An object, such as a tool, weapon or household utensil, made by human craftsmen; especially, an item of prehistoric craftsmanship that indicates the degree of advancement of the society to which the craftsman belonged.

An Indian arrowhead is an ARTIFACT.

artificial satellite \ˌärt-ə-'fish-əl 'sat-ᵊl-ˌīt\
ASTRONAUTICS. A man-made object propelled into space at a

speed and angle sufficient to put it into orbit around the earth or some other celestial body.

An ARTIFICIAL SATELLITE *may be used to relay radio and television signals.*



ARTIFICIAL SATELLITE

asbestos \as-ˈbes-təs\ *n.*

EARTH SCIENCE. A fibrous, incombustible mineral used in making fireproof materials.

Furnace pipes are often wrapped with sheets made of ASBESTOS.

aseptic \(ˈ)ā-ˈsep-tik\ *adj.*

MEDICINE. Free from microorganisms that cause infection.

ASEPTIC *surgical dressings were first used by Joseph Lister.*

asexual reproduction \(ˈ)ā-ˈseksh-(ə)wəl ˌrē-prə-ˈdək-shən\

BIOLOGY. A kind of reproduction characteristic of some forms of life, both plant and animal, that does not involve the union of male and female reproductive cells; budding and fission.

Bacteria increase by means of ASEXUAL REPRODUCTION.

ASH

ash \ˈash\ *n.*

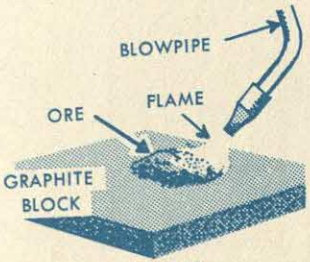
CHEMISTRY. The inorganic residue remaining after the burning of combustible substances, such as wood.

Some substances are completely combustible and leave no ASH.

aspirin \ˈas-p(ə-)rən\ *n.*

MEDICINE. $C_6H_4COOHCOOCH_3$. A common drug, the acetate of salicylic acid.

ASPIRIN *may be used upon the advice of a physician to reduce pain.*



ASSAY
(By oxidation-reduction)

assay \ˈas-ˌā\

1. CHEMISTRY (N.). A chemical test to determine the amount of gold, silver or other metal in an ore or alloy. 2. BIOLOGY (V.). To determine the effect of a drug, or other substance, on living biological material, in comparison with the effect of a standardized product on the same material.

Miners depend upon an ASSAY *to determine the value of their ore.*

assimilation \ə-ˌsim-ə-ˈlā-shən\ *n.*

PHYSIOLOGY. The conversion into living tissue of ingested and digested food; anabolism.

ASSIMILATION *is necessary for cell growth.*

associative law \ə-'so-s(h)ē-ˌāt-iv 'lȯ\

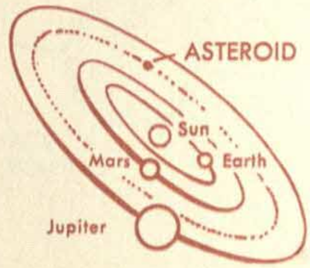
MATHEMATICS. An operation in which three terms, or elements, are combined, the result being independent of the manner in which they are grouped.

The ASSOCIATIVE LAW *applies to the addition of integers where, if a, b and c are any three integers, then* $a + (b + c) = (a + b) + c$.

assumptions \ə-'səm(p)-shənz\ *n.*

MATHEMATICS. Statements taken for granted without proof; acts of assuming.

A mathematician makes use of ASSUMPTIONS *in building mathematical axioms and postulates.*



asteroid \'as-tə-ˌrȯid\ *n.*

ASTRONOMY. A small, irregularly-shaped planet, many of which orbit the sun in a path between Mars and Jupiter.

Ceres, the largest-known ASTEROID, *is about 480 miles in diameter.*

astigmatism \ə-'stig-mə-ˌtiz-əm\ *n.*

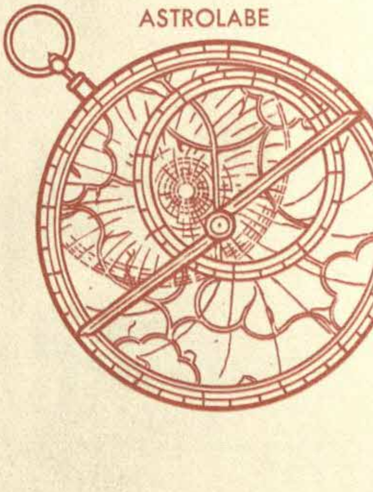
1. MEDICINE. Irregular curvature of the cornea or the lens of the eye that results in an improper focus of light rays on the retina. 2. PHYSICS. A lens defect in which light rays are not correctly focused.

Specially-ground spectacle lenses can usually offset the effects of ASTIGMATISM.

astral \'as-trəl\ *adj.*

ASTRONOMY. Of or relating to the stars.

ASTRAL *observations were made by the ancient Greeks.*



astringent \ə-'strin-jənt\ *n.*

MEDICINE. A substance that contracts body tissues.

Ice is a common ASTRINGENT.

astrogation \ˌas-trə-'gā-shən\ *n.*

ASTRONAUTICS. Navigation in outer space using celestial bodies for reference points; also called astronavigation.

The explorers of space will employ ASTROGATION *in exploring distant galaxies.*

astrolabe \'as-trə-ˌlāb\ *n.*

ASTRONOMY. A circular brass or bronze astronomical instrument with a pointer pivoting at the center, first used by the ancient

Greeks to observe and measure the altitude of celestial bodies.

The ASTROLABE, *sometimes used as a teaching device today, preceded the quadrant and the sextant.*

astronaut \ˈas-trə-ˌnȯt\ *n.*
AERONAUTICS. A pilot carefully selected and specially trained for flights into space.

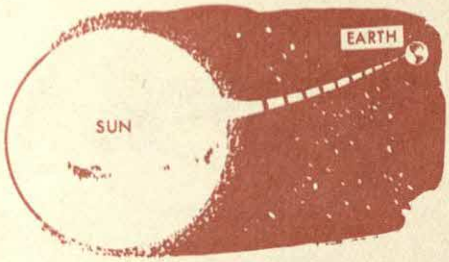
An ASTRONAUT *must undergo rigorous physical and mental training.*

astronautics \ˌas-trə-ˈnȯt-iks\ *n.*
The science of space flight.

The science of ASTRONAUTICS *includes the construction and use of rockets, satellites and other devices used in space travel.*

astronomer \ə-ˈsträn-ə-mər\ *n.*
ASTRONOMY. A scientist who studies the positions, movements, sizes, physical features and makeup of planets, stars and other objects and materials in the universe.

An ASTRONOMER *uses telescopes, spectroscopes and many other instruments to find out about celestial bodies.*



ASTRONOMICAL
UNIT
92,907,000 Miles

astronomical unit \ˌas-trə-ˈnäm-i-kəl ˈyü-nət\
ASTRONOMY. The mean distance of the earth from the sun, equal to approximately 92,907,000 miles.

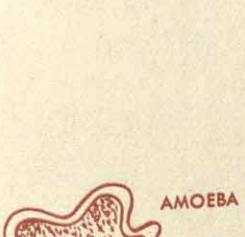
The ASTRONOMICAL UNIT *is used to measure much shorter distances than the light-year.*

astronomy \ə-ˈsträn-ə-mē\ *n.*
The study of celestial bodies and the oldest of all sciences.

The telescope is one of the important tools of ASTRONOMY.

astrophysics \ˌas-trə-ˈfiz-iks\ *n.*
ASTRONOMY. The science dealing with the application of laws and principles of physics to all aspects of astronomy.

The science of ASTROPHYSICS *will be developed more and more during the space age.*



ASYMMETRICAL

asymmetrical \ˌā-sə-ˈme-tri-kəl\ *adj.*
Having an unbalanced shape; not symmetrical.

The amoeba is an ASYMMETRICAL *animal.*

ataxite \ə-ˈtak-ˌsīt\ *n.*
EARTH SCIENCE. A taxite that consists of angular fragments.

The ATAXITE *was a mass of different colors and textures.*

atherosclerosis \ˌath-ə-rō-sklə-ˈrō-səs\ *n.*

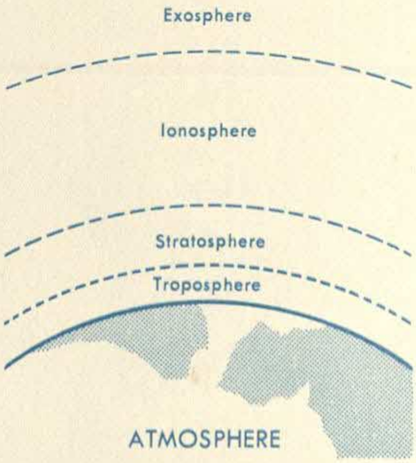
MEDICINE. A disease phase of arteriosclerosis characterized by deposits of fat within large arteries and resulting in the narrowing and hardening of such arteries.

When ATHEROSCLEROSIS *affects blood vessels in the heart, the condition is known as angina pectoris.*

atmosphere \ˈat-mə-ˌsfi(ə)r\ *n.*

1. EARTH SCIENCE. The gaseous matter surrounding the earth and other celestial bodies. 2. PHYSICS. A unit of pressure, defined as the pressure of a column of mercury 760 mm. high, of 0° C. temperature, at sea level. 3. CHEMISTRY. A mass of gas occupying a region where it promotes or prevents a chemical reaction.

In general, the density of the ATMOSPHERE *is greater near the earth's surface.*



atmospheric pressure \ˌat-mə-ˈsfi(ə)r-ik ˈpresh-ər\

EARTH SCIENCE. The pressure exerted in every direction at a given point by the weight of the atmosphere, generally expressed in inches of mercury and varying according to altitude.

ATMOSPHERIC PRESSURE *is greatest at sea level.*

atoll \ˈat-ˌȯl\ *n.*

EARTH SCIENCE. An island of coral encircling a lagoon.

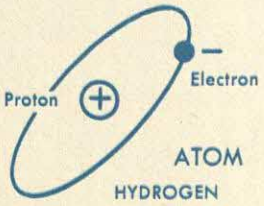
An ATOLL *is a type of island found in the Indian Ocean.*

HORSESHOE ISLAND
(CORAL)

atom \ˈat-əm\ *n.*

CHEMISTRY and PHYSICS. The unit particle of an element, composed of protons, neutrons and electrons; also, the smallest particle of an element that, except for inert elements, can enter into chemical combination with the atoms of other elements.

The hydrogen ATOM, *containing one electron and one proton, is the lightest atom.*



atomic energy \ə-ˈtäm-ik ˈen-ər-jē\

PHYSICS. Energy that is released when the nuclei of atoms are disintegrated through atomic fission or combined through atomic fusion.

A large amount of ATOMIC ENERGY *can be produced from a small amount of matter.*

atomic fission \ə-ˈtäm-ik ˈfish-ən\

PHYSICS. The process in which atomic nuclei are split, resulting in a release of energy; in a chain reaction, the splitting of an atomic nucleus, resulting in the release of neutrons which split other nuclei, in turn releasing other neutrons, and so on.

Man is already beginning to use ATOMIC FISSION *to supply power for home and industry.*

atomic fusion \ə-'täm-ik 'fyü-zhən\

PHYSICS. The forcing together of the nuclei of particular atoms by means of great energy, producing atoms of greater complexity and releasing large amounts of energy; for example, the fusion of hydrogen atoms that produces helium atoms in the sun.

The hydrogen bomb is one result of man-made ATOMIC FUSION.

ATOMIC FUSION

atomic mass \ə-'täm-ik 'mas\

PHYSICS. The mass of an atom, or any species of atom.

ATOMIC MASS *is generally represented by atomic mass units.*

atomic number \ə-'täm-ik 'nəm-bər\

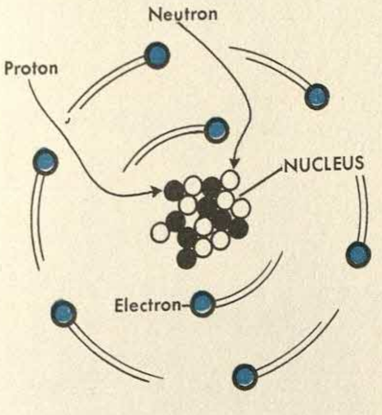
CHEMISTRY and PHYSICS. The number of protons, varying from element to element, found in the nucleus of an atom.

The ATOMIC NUMBER *of aluminum is 13.*

atomic structure \ə-'täm-ik 'strək-chər\

CHEMISTRY and PHYSICS. The arrangement of the component parts of the atom: the atomic nucleus, consisting of protons and neutrons, and the surrounding shell, or shells, of electrons.

The nature of ATOMIC STRUCTURE *is increasingly revealed through scientific research.*



ATOMIC STRUCTURE

atomic weight \ə-'täm-ik 'wāt\

CHEMISTRY and PHYSICS. The relative weight of an atom of an element compared with an atom of another element taken as a standard for comparison, the standard being the carbon isotope of mass 12 (atomic weight units).

Until 1961, the agreed-upon standard was oxygen with an ATOMIC WEIGHT *of 16.*

ATP

The abbreviation for adenosine triphosphate. See *adenosine triphosphate.*

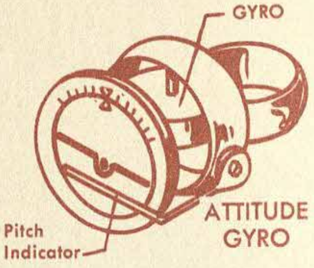
atrophy \'a-trə-fē\ *v.*

BIOLOGY. Of tissues, to waste away because of disease, lack of nourishment or disuse.

If not exercised, muscles will ATROPHY.

attitude gyro \'at-ə-ˌt(y)üd 'jī(ə)r-(ˌ)ō\
AERONAUTICS. A mechanism operated by a gyroscope, used to provide airplanes with an artificial horizon, so that the attitude of the airplane in relation to the earth can be determined.

The ATTITUDE GYRO *is a valuable aid to a pilot flying in rough weather.*

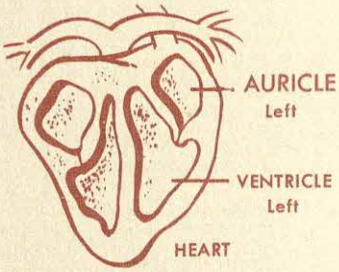


attitude jets \'at-ə-ˌt(y)üd 'jets\
ASTRONAUTICS and ENGINEERING. Small rockets used to stabilize and maneuver a spacecraft in space; also called control jets.

The ATTITUDE JETS *on Mercury and Gemini spacecraft were powered by a liquid propellant.*

auditory \'ȯd-ə-ˌtōr-ē\ *adj.*
ANATOMY and ZOOLOGY. Pertaining to the sense or organs of hearing.

In general the AUDITORY *organs of dogs are more sensitive to higher frequencies than are human ears.*



auricle \'ȯr-i-kəl\ *n.*
ANATOMY and ZOOLOGY. Either of the two chambers of the heart that receives blood from the veins; also, the part of the ear that can be seen.

Blood in the heart is pumped from each AURICLE *into a ventricle.*

aurora australis \ə-'rōr-ə (ˌ)ȯ-'strā-ləs\
ASTRONOMY. A natural display of light streamers believed to be caused by electrical disturbances in the atmosphere, radiating in a fanlike pattern from the antarctic region and visible for great distances.

The AURORA AUSTRALIS *in the Southern Hemisphere corresponds to the aurora borealis in the Northern Hemisphere.*

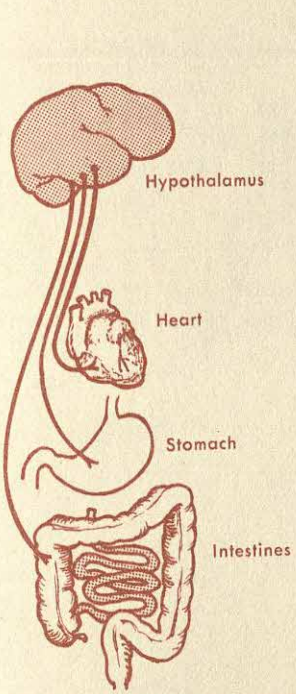
aurora borealis \ə'rōr-ə ˌbōr-ē-'al-əs\
ASTRONOMY. A natural display of light streamers thought to be caused by electrical disturbances in the atmosphere, radiating in a fanlike pattern from the arctic region and visible for great distances; the northern lights.

Long ago, people believed the appearance of the AURORA BOREALIS *was an evil omen.*

automatic programming \ˌȯt-ə-'mat-ik 'prō-ˌgram-iŋ\
ENGINEERING and MATHEMATICS. A procedure by which a digital

computer automatically produces partial or complete programs in a language that the computer can process.

Through AUTOMATIC PROGRAMMING, *certain computers convert problem-oriented data to machine-oriented data.*



AUTONOMIC NERVOUS SYSTEM

automation \ˌȯt-ə-ˈmā-shən\ *n.*
ENGINEERING. Work performed by mechanisms that are self-regulating or automatic; especially, a series of such mechanisms for the refining or manufacture of products.

AUTOMATION *has increased the production and availability of goods and services without a proportional increase in manual labor.*

autonomic nervous system \ˌȯt-ə-ˈnäm-ik ˈnər-vəs ˈsis-təm\
PHYSIOLOGY. The part of the peripheral nervous system that controls involuntary body functions, such as breathing, heartbeat and digestion.

The AUTONOMIC NERVOUS SYSTEM *functions even during sleep.*

autopsy \ˈȯ-ˌtäp-sē\ *n.*
MEDICINE. An examination of a dead body, in the course of which the body may be partially dissected, in order to determine either the cause of death, or the nature of the disease or other abnormality that caused death.

An AUTOPSY *is often performed to increase our knowledge of medicine.*

AUTOTROPH

autotroph \ˈȯt-ə-ˌträf\ *n.*
BIOLOGY. An organism capable of carrying on nutrition by using inorganic materials combined with energy to synthesize the organic foods it requires for life; an organism capable of using CO_2 or carbonates as a sole source of carbon.

A photosynthetic AUTOTROPH *uses light energy for food production.*

autunite \ō-ˈtən-ˌīt\ *n.*
EARTH SCIENCE. $CaU_2P_2O_{12} \cdot 8H_2O$. A minor ore of uranium, occurring as a yellowish, radioactive calcium phosphate in crystals and tabular scales.

AUTUNITE *was first found in France.*

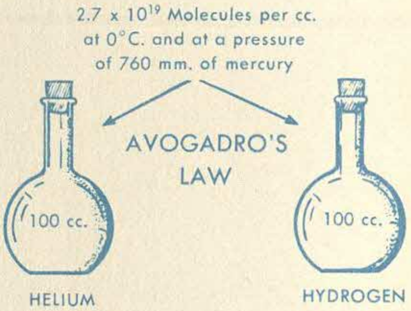
average \ˈav-(ə-)rij\ *n.*
MATHEMATICS. The sum of two or more quantities divided by the number of quantities; a mean value.

The AVERAGE *of 6, 8, 10 and 12 is 9.*

Avogadro's law \ˌav-ə-'gäd-(ˌ)rōz 'lȯ\

CHEMISTRY and PHYSICS. The statement, originally presented as a hypothesis by Amadeo Avogadro in 1811, that all gases in equal volumes, maintained at identical pressure and temperature, have an identical number of molecules.

AVOGADRO'S LAW *is a basic law of modern chemistry.*


2.7 x 10^{19} Molecules per cc. at 0°C. and at a pressure of 760 mm. of mercury
AVOGADRO'S LAW
100 cc.
100 cc.
HELIUM
HYDROGEN

Avogadro's number \ˌav-ə-'gäd-(ˌ)rōz 'nəm-bər\

CHEMISTRY and PHYSICS. A number that represents the quantity of molecules present in a standard unit of gas, called one gram-molecular volume, or a standard unit of weight, called one gram-molecular weight. Since the number is so large, it is usually written as 6.02×10^{23}.

AVOGADRO'S NUMBER *can be determined by different kinds of scientific experiments.*

axiom \'ak-sē-əm\ *n.*

MATHEMATICS. A statement that, in a mathematical system, is accepted as being true without proof, and that is used in solving problems and in proving other statements.

"If equals are added to equals, the sums are equal" is an important AXIOM *of arithmetic.*

axis \'ak-səs\ *n.*

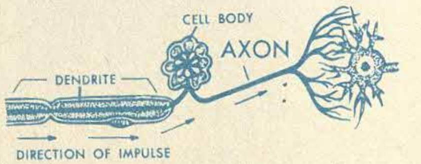
1. MATHEMATICS. A straight line, real or imaginary, that passes through the center of a symmetrical object and around which the object may actually or theoretically rotate, such as the earth's axis; also, any one of the reference lines of a coordinate system, as the vertical axis and the horizontal axis of a rectangular coordinate system. 2. ANATOMY. The second vertebra of the neck.

The earth's AXIS *is an imaginary line passing through the poles.*

axon \'ak-ˌsän\ *n.*

ANATOMY and PHYSIOLOGY. The part of a nerve cell fiber that carries impulses away from the main cell body.

In most neurons, the AXON *is longer than the dendrite.*

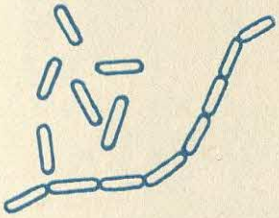


azimuth \'az-(ə-)məth\ *n.*

ASTRONOMY. The arc of the horizon measured clockwise between a fixed point, the south point or the north point, and a vertical circle, or plane, passing through the object.

A star in the western sky has an AZIMUTH *of 90 or 270 degrees, depending on which fixed point is used.*

B



BACILLUS

babbit \'bab-ət\ *n.*

ENGINEERING. An alloy composed of differing amounts of tin, copper and antimony and used to line the bearings of machinery.

BABBIT, *a metal, was named for an American inventor and is sometimes called Babbit's metal.*

bacillus \bə-'sil-əs\ *n.*

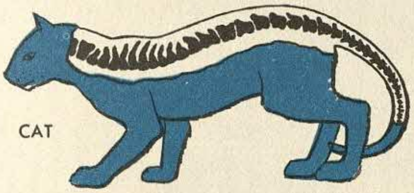
BIOLOGY. A genus of rod-shaped, aerobic bacteria.

One species of BACILLUS *causes diphtheria.*

backbone \'bak-ˌbōn\ *n.*

ANATOMY and ZOOLOGY. A column of bones, called vertebrae, that serves as the main structural support for the body in man and in other vertebrates; the spine.

The BACKBONE *serves as a basis for classifying certain members of the animal world.*



BACKBONE

background count \'bak-ˌgraund 'kau̇nt\

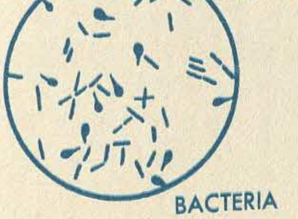
PHYSICS. That radiation count (in measurements of radioactivity) produced by such causes as cosmic rays or local contamination, rather than by the radiation coming from the source under study.

The Geiger counter generally picks up a BACKGROUND COUNT.

bacteria \bak-'tir-ē-ə\ *n.*

BIOLOGY. Microscopic, one-celled organisms found in water, soil, air and in living and nonliving organic matter. Some cause disease, while others, such as those found in the soil, serve to break down matter.

Individual BACTERIA *cannot be seen without the aid of a microscope.*



BACTERIA

bactericide \bak-'tir-ə-ˌsīd\ *n.*

MEDICINE. Any substance that kills bacteria.

Tincture of iodine is an effective BACTERICIDE.

bacteriologist \(ˌ)bak-ˌtir-ē-ˈäl-ə-jəst\ *n.*

A scientist who studies bacteria, their characteristics, behavior and effects on living organisms.

A BACTERIOLOGIST *is often included on research teams that are investigating the causes and control of diseases.*

bacteriology \(ˌ)bak-ˌtir-ē-ˈäl-ə-jē\ *n.*

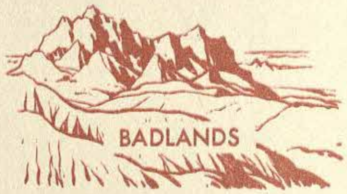
BIOLOGY. The science concerned with the study of bacteria.

BACTERIOLOGY *is a relatively-new science.*

bacteriophage \bak-ˈtir-ē-ə-ˌfāj\ *n.*

BIOLOGY. A virus, enzyme or other bacteria-killing agent.

More than one kind of BACTERIOPHAGE *is normally present in the intestinal tract of animals.*



badlands \ˈbad-ˌlandz\ *n.*

EARTH SCIENCE. A nearly barren region where erosion has cut the land into an intricate system of sharp-crested hills and narrow ravines.

The BADLANDS *were so named because of the dangers involved in crossing them.*

baking soda \ˈbāk-iŋ ˈsōd-ə\

CHEMISTRY. $NaHCO_3$. Sodium bicarbonate.

BAKING SODA *dissolved in water forms an alkaline solution.*

balance \ˈbal-ən(t)s\ *n.*

1. CHEMISTRY. The mathematical adjustment of the numbers of atoms of each element in an equation for a chemical reaction so that the total number of atoms of a given element in the reactant or reactants is the same as the total in the product or products. 2. PHYSICS. The stability achieved when opposing forces are equalized. 3. A device for weighing.

The equation $2H_2 + O_2 = 2H_2O$ *is in* BALANCE.

balanced diet \ˈbal-ən(t)st ˈdī-ət\

BIOLOGY. A proportion of different foods that satisfies major nutritional requirements of an organism.

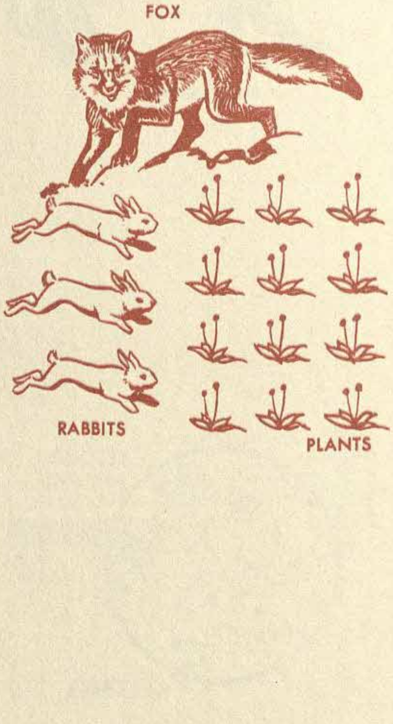
A BALANCED DIET *is necessary for good health.*

balance of nature \ˈbal-ən(t)s əv ˈnā-chər\

BIOLOGY. A balance of population among the various plants and animals in a given area; sometimes referred to as natural equilibrium.

Destroying the foxes in a given area can upset the BALANCE OF NATURE *that exists among foxes, rabbits and plants.*

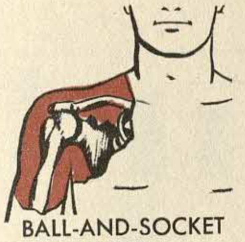
BALANCE OF NATURE



ball-and-socket joint \'bȯl ənd 'säk-ət 'jȯint\

ANATOMY. A joint formed by a round-headed bone that fits into a cavity of an adjacent bone, thus permitting circular or universal movement within the limitations of the muscles.

A BALL-AND-SOCKET JOINT *is found in the shoulder of the human being.*



ballast \'bal-əst\ *n.*

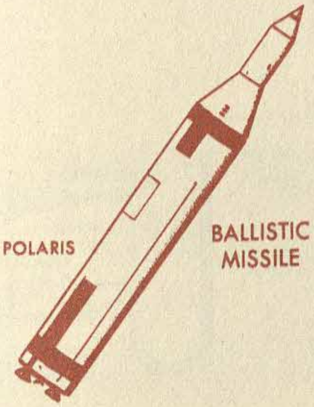
AERONAUTICS. Sand or other heavy material placed within an airplane, ship or other vehicle to change its weight or to improve its stability by changing its center of gravity.

An airship can be made to rise by throwing BALLAST *overboard.*

ball bearing \'bȯl 'ba(ə)r-iŋ\

ENGINEERING. A device that reduces friction by using metallic balls, generally steel, in a circular track to support a revolving shaft.

Roller-skate wheels turn freely because each one is supported by a BALL BEARING.



ballistic missile \bə-'lis-tik 'mis-əl\

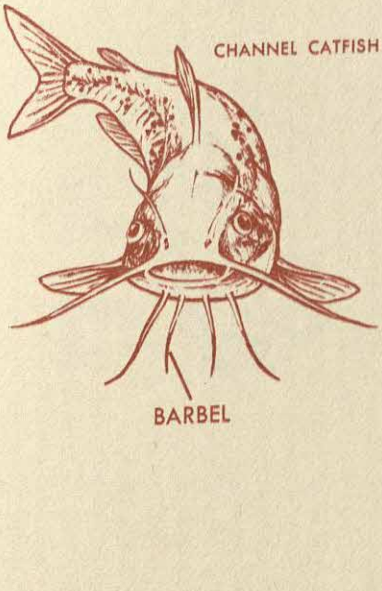
ASTRONAUTICS. An unmanned vehicle that is predirected to follow a certain flight trajectory and that becomes an unpowered, free-falling body in the last stage of flight.

The BALLISTIC MISSILE *was developed during World War II.*

ballistics \bə-'lis-tiks\ *n.*

The science dealing with the motion, behavior and effect of projectiles.

The study of BALLISTICS *depends upon a knowledge of mathematics.*



bar \'bär\ *n.*

PHYSICS. A standard unit for measuring pressure, equal to one million dynes per square cm.

A BAR *is slightly less than one atmosphere of pressure.*

barbel \'bär-bəl\ *n.*

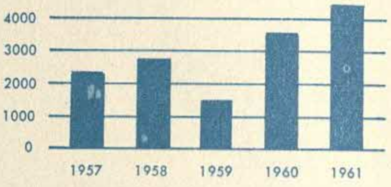
ZOOLOGY. A slender, fleshy, whiskerlike filament, occurring near the mouth of certain fishes.

The BARBEL *of a fish helps it find food at the bottom of a river.*

barbiturates \bär-'bich-ə-rəts\ *n.*

CHEMISTRY. A large group of drugs derived from barbituric acid, $C_4H_4N_2O_3$, and used as sedatives and hypnotics.

Because medically-unsupervised use of BARBITURATES *may cause addiction, they are legally available only by prescription.*



BAR GRAPH

bar graph \'bär 'graf\

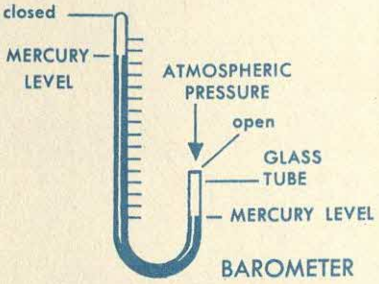
MATHEMATICS. A diagram showing quantities in a set of data. The diagram consists of heavy vertical or horizontal lines, or bars, whose lengths are proportional to the size of the quantities.

Business organizations sometimes use a BAR GRAPH *to illustrate a change in sales or production over a period of time.*

bark \'bärk\ *n.*

1. BOTANY. The external covering of a woody perennial, such as a tree. 2. ZOOLOGY. The sound made by certain animals, such as dogs.

The active tissue in a woody stem, called the cambium, is protected by the BARK.



BAROMETER

barograph \'bar-ə-ˌgraf\ *n.*

EARTH SCIENCE. A device that automatically records changes in atmospheric pressure; a recording barometer.

Weather stations use the BAROGRAPH *in making weather forecasts.*

barometer \bə-'räm-ət-ər\ *n.*

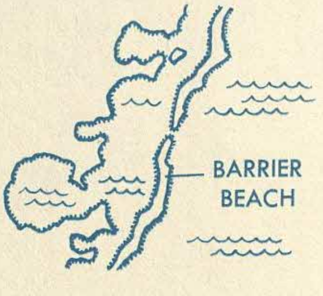
EARTH SCIENCE. A device for measuring atmospheric pressure, used to predict weather and to determine changes in altitude.

A BAROMETER *may be one of two types, either mercury or aneroid.*

barometric pressure \ˌbar-ə-'met-rik 'presh-ər\

EARTH SCIENCE. The pressure of the earth's atmosphere as indicated by a barometer.

Changes in BAROMETRIC PRESSURE *often precede changes in the weather.*



barrier beach \'bar-ē-ər 'bēch\

EARTH SCIENCE. An elongated island formed by waves depositing loose material that eventually rises above sea level; a sandy island parallel to the shore; an offshore bar.

The body of water between a BARRIER BEACH *and the shore is called a lagoon.*

barrier reef \'bar-ē-ər 'rēf\

EARTH SCIENCE. A long, narrow wall of coral rock lying just below or above the surface of the sea, found near the coast of an island or continent.

Small boats sometimes run aground on a BARRIER REEF.

BASALT

basal metabolism \'bā-səl mə-'tab-ə-ˌliz-əm\

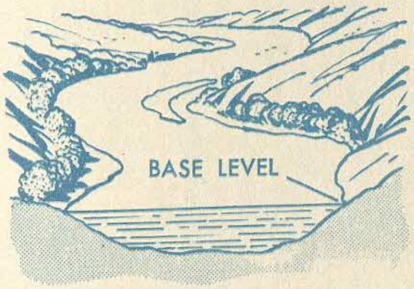
PHYSIOLOGY. The minimal energy required to maintain the body in a resting state 14 to 18 hours after eating.

BASAL METABOLISM *is measured in units of calories per hour per square meter of body surface.*

basalt \bə-'sȯlt\ *n.*

EARTH SCIENCE. A fine-grained igneous rock, gray to black, containing plagioclase and pyroxene.

BASALT *sometimes contains magnetite or lodestones.*



base \'bās\ *n.*

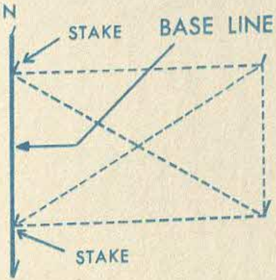
1. MATHEMATICS. A side of a plane figure, extended if necessary, or a plane surface of a solid, to which an altitude is drawn; also, a number used in counting to show the size of a reference set that is repeated as a group in the counting process. In a numeration system in which the value of a digit depends upon its position or place in the numeral, the base is the number of units required in any given position to equal one unit in the position to its left. 2. CHEMISTRY. A compound that produces hydroxyl ions in solution, reacts with and neutralizes acids to form salts and turns red litmus paper blue.

The BASE *of our decimal system of numeration is ten, because it requires ten units in the hundreds place to equal one unit in the thousands place.*

base level \'bās 'lev-əl\

EARTH SCIENCE. Theoretically, the lowest level to which water can erode land.

The surface of the water in a river forms the BASE LEVEL *of the land it drains.*



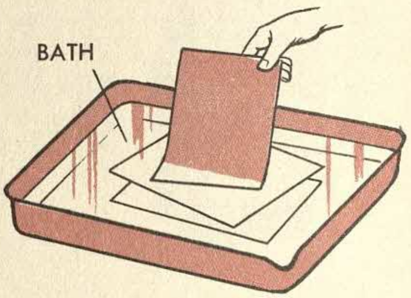
base line \'bās 'līn\

ENGINEERING. A line of established length and direction used in surveying to fix other directions and positions.

The surveyor placed stakes 100 yards apart to designate his BASE LINE.

base metal \'bās 'met-ᵊl\
CHEMISTRY. Any metal of relatively-low value, or one that is inferior in some characteristic, such as resistance to corrosion or infusibility.

Lead is a very useful BASE METAL.



basic \'bā-sik\ *adj.*
CHEMISTRY. Pertaining to, or having the characteristics of, a base; see *base* (2).

In a chemical formula, the ingredient that provides hydroxide $(OH)^-$ ions is regarded as BASIC.

basic anhydride \'bā-sik (')an-'hī-ˌdrīd\
CHEMISTRY. An oxide of metal formed by removing the water from a base, or that, when added to water, forms a base.

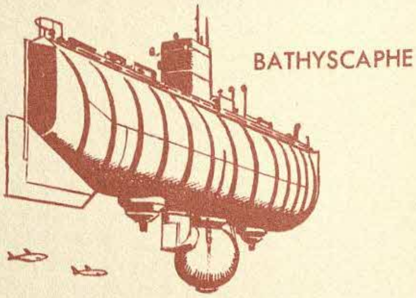
Some household disinfectants of the dry type are composed of a BASIC ANHYDRIDE.

basic salt \'bā-sik 'sȯlt\
CHEMISTRY. A salt that contains one or more hydroxide radicals or that, when dissolved in water, produces such radicals.

A solution of a BASIC SALT *changes the color of red litmus to blue.*

basin \'bās-ᵊn\ *n.*
EARTH SCIENCE. A natural depression in the earth, large or small, surrounded by higher land.

A BASIN *frequently contains a body of water, such as a pond or lake.*



bath \'bath\ *n.*
CHEMISTRY. A solution or chemical preparation in which something is immersed.

Photographers use an acid BATH *to make prints permanent.*

batholith \'bath-ə-ˌlith\ *n.*
EARTH SCIENCE. A large mass of igneous rock lying below the earth's surface and extending to unknown depths.

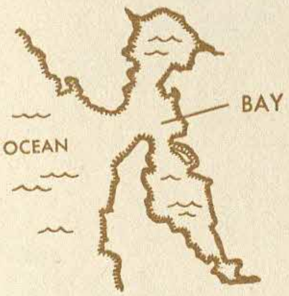
The core of some mountain ranges is a BATHOLITH.

bathyscaphe \'bath-i-ˌskaf\ *n.*
EARTH SCIENCE. A powered vehicle for deep-sea exploring that can be controlled from a cabin or compartment attached to its underside.

A BATHYSCAPHE *has powerful lights for viewing the ocean floor at great depths.*

bathysphere \'bath-i-ˌsfi(ə)r\ *n.*
EARTH SCIENCE. A spherical diving compartment used for studying deep-sea life.

In 1930, William Beebe made his first descent in a BATHYSPHERE *to study undersea life.*



battery \'bat-ə-rē\ *n.*
ENGINEERING. A combination of two or more chemical cells connected electrically to produce an electric current.

A BATTERY *produces direct current.*

Baumé scale \bō-'mā 'skāl\
CHEMISTRY and PHYSICS. Either of two hydrometric scales used to measure the density of liquids: one for liquids heavier than water, the other for liquids lighter than water.

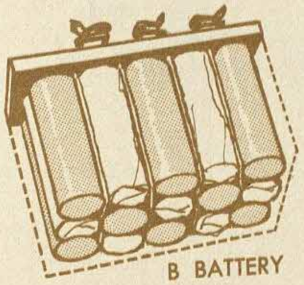
The BAUMÉ SCALE *is named for the French chemist, Antoine Baumé, who invented the Baumé hydrometer.*

bauxite \'bȯk-ˌsīt\ *n.*
CHEMISTRY and EARTH SCIENCE. $Al_2O_3 \cdot 2H_2O$. The principal ore of aluminum, consisting chiefly of aluminum oxide or hydroxide with various impurities.

Most of the BAUXITE *produced in the United States comes from the Little Rock, Arkansas, area.*

bay \'bā\ *n.*
1. EARTH SCIENCE. An inlet of a sea or lake, smaller than a gulf and larger than a cove. 2. ZOOLOGY. An animal of chestnut coloring, usually a horse; also, the cry of a dog, coyote, wolf or similar animal.

A BAY *is often used for mooring boats because it is sheltered from the wind.*



bayou \'bī-(ˌ)(y)ō\ *n.*
EARTH SCIENCE. A small secondary river or stream with a sluggish or obstructed current.

A BAYOU *is often characterized by swamplike vegetation.*

B battery \'bē 'bat-ə-rē\
ENGINEERING. An electric battery connected in the plate circuit of an electron tube to cause the flow of electrons in that circuit.

A voltage of 22½, or multiples of that amount, is usually supplied by a B BATTERY.

BCD

An abbreviation for binary coded decimal. See *binary coded decimal.*

B-complex vitamins \'bē 'käm-ˌpleks 'vīt-ə-mənz\

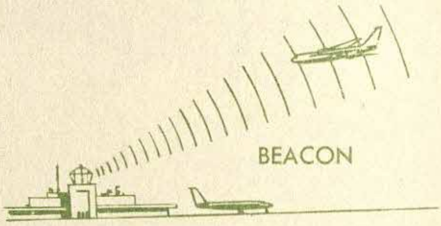
MEDICINE. A large group of water-soluble compounds, such as thiamine, riboflavin and niacin, necessary in adequate quantity to prevent certain diet-deficiency diseases.

One of the B-COMPLEX VITAMINS *is vitamin* B_1*, or thiamine, that is found in such foods as cereals and yeast.*

beach \'bēch\ *n.*

EARTH SCIENCE. A nearly-level stretch of pebbly or sandy shore that is washed by the high tides or high waters of a sea, lake or river.

The sand on a BEACH *is produced from rock fragments by the grinding action of waves.*



BEACON

beacon \'bē-kən\ *n.*

AERONAUTICS and ASTRONAUTICS. A light or radio beam that serves as a guide or warning for pilots of air or spacecraft, or for vessels at sea.

A pilot may depend on a radio BEACON *to indicate the correct approach to an airfield in bad weather.*

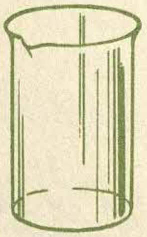
bead test \'bēd 'test\

CHEMISTRY. A qualitative test for an element, generally based on the color produced when a sample is reacted by heating with a bead of a known substance formed on a small loop of inert wire.

A BEAD TEST *generally depends upon a bead of borax fused within a loop of platinum wire.*

beaker \'bēk-ər\ *n.*

CHEMISTRY. A flat-bottomed, cylindrical container with a pouring lip, used by pharmacists, laboratory technicians and chemists.



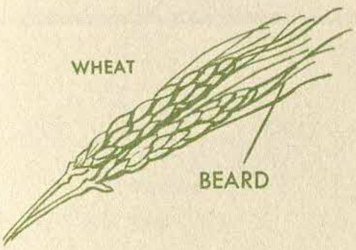
BEAKER

A glass BEAKER *is often used to decant liquids—that is, to pour the liquid carefully from the beaker without disturbing the solid material that has settled to the bottom.*

beam \'bēm\ *n.*

1. AERONAUTICS. A radio or radar signal from the ground that is used as a navigation guide by pilots. 2. ZOOLOGY. The main part of a stag's horn from which the antlers stem.

Navigation by use of a radio BEAM *makes flying safer at night and in bad weather.*



beard \'bi(ə)rd\ *n.*

1. BOTANY. Bristly appendages on some plants, such as on the grain of wheat or barley. 2. ZOOLOGY. A tuft of hair on some animals or of feathers on certain birds.

Ripening wheat and barley are characterized by a BEARD.

bearing \'ba(ə)r-iŋ\ *n.*

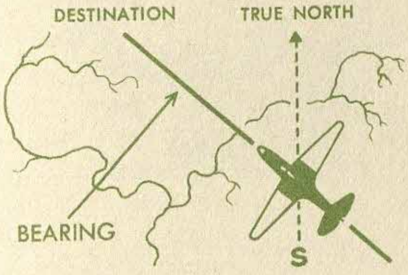
AERONAUTICS and EARTH SCIENCE. The horizontal direction of a line drawn from one object to another with reference to either true or magnetic north.

The BEARING *found with a compass is magnetic north and must be corrected to find true north.*

bearings \'ba(ə)r-iŋz\ *n.*

ENGINEERING. Supports that hold revolving shafts or other machine parts in position.

Shafts designed to rotate at high speeds are usually supported by ball BEARINGS.



beat \'bēt\ *n.*

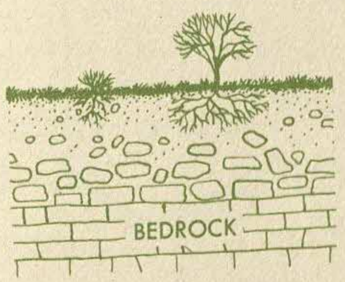
PHYSICS. The regular pulsation or amplitude change that occurs when sounds, radio waves or electrical currents of slightly-different frequencies are combined.

Electronic devices used to measure wave frequency depend on the BEAT *to locate proper wavelength settings.*

Beaufort wind scale \'bō-fərt 'wind 'skāl\

EARTH SCIENCE. A scale denoting wind force, graded from 0 to 17. It applies to speeds from 0 miles per hour (calm) to 73 miles per hour or more (hurricane).

The BEAUFORT WIND SCALE *is the standard international measure of wind speed.*



bedrock \'bed-'räk\ *n.*

EARTH SCIENCE. Solid rock lying beneath a layer of soil, sand, clay or rock fragments; also, solid rock exposed at the earth's surface.

Construction engineers attempt to place the foundations for large buildings on BEDROCK.

bel \'bel\ *n.*

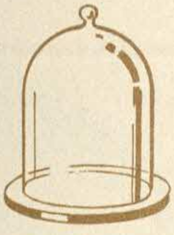
PHYSICS. A unit of a logarithmic scale used in radio and telegraphy to express the ratios of two amounts of power or voltage.

The BEL *can be used with reference to the volume of sound.*

bell jar \'bel 'jär\

PHYSICS. A bell-shaped glass container used to hold gases or to create a vacuum.

The BELL JAR *is constructed to withstand internal pressure.*



BELL JAR

belly \'bel-ē\ *n.*

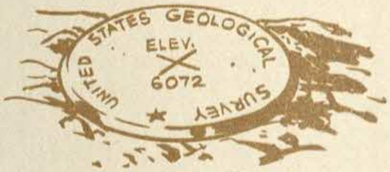
1. ZOOLOGY. The soft underside or abdomen of an animal.
2. ANATOMY. The fleshy part of a muscle.

Because it has no bony protection, the BELLY *of most animals is vulnerable to attack by their enemies.*

bench mark \'bench 'märk\

EARTH SCIENCE. A mark made in a permanent landmark having a known position and altitude, used as a reference point from which to measure other altitudes.

In the absence of a permanent landmark, a surveyor may set up a stake on which to make a temporary BENCH MARK.



BENCH MARK

bends \'ben(d)z\ *n.*

PHYSIOLOGY. Severe pains in the limbs and abdomen caused by a rapid decrease of air pressure on the body that results in the formation of nitrogen bubbles in the blood.

A diver suffering from the BENDS *is usually placed in a compression chamber and subjected to pressure that is gradually decreased to atmospheric pressure.*

benign \bi-'nīn\ *adj.*

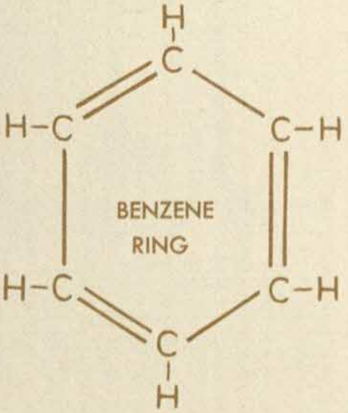
MEDICINE. Referring to a condition or growth that is not severe in its effect; nonmalignant.

A biopsy can determine whether a tumor is BENIGN *or malignant.*

benthos \'ben-ˌthäs\ *n.*

BIOLOGY and EARTH SCIENCE. The sea bottom in the deepest parts of the ocean; also, all the flora and fauna, taken collectively, that are found on the bottom of a body of water.

The BENTHOS *is the habitat of a number of sedentary organisms.*



BENZENE RING

benzene \'ben-ˌzēn\ *n.*

CHEMISTRY. C_6H_6. A volatile, colorless, flammable and aromatic hydrocarbon obtained from coal tar.

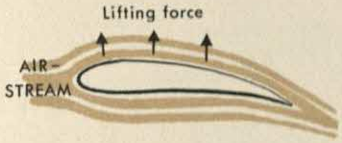
The major use of BENZENE *is in the production of other chemicals, as phenol and styrene.*

benzene ring \'ben-ˌzēn 'riŋ\

CHEMISTRY. The basic structural formula for the benzene molecule; a closed chain, or ring, of six carbon atoms, to each of which is attached a hydrogen atom or other univalent atom or radical.

In the BENZENE RING, *the six carbon atoms are joined alternately by single and double bonds.*

BERNOULLI'S PRINCIPLE

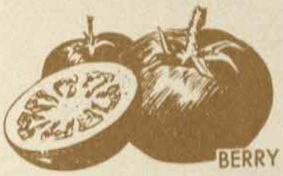


AIRPLANE WING

berkelium \'bər-klē-əm\ *n.*
CHEMISTRY. A radioactive chemical element that does not occur naturally on earth. It is produced by bombarding americium with high-energy alpha particles. Symbol, Bk; atomic number, 97; atomic weight, 249.

BERKELIUM *derives its name from the University of California at Berkeley, where it was first produced.*

Bernoulli's principle \bər-'nü-lēz 'prin(t)-s(ə-)pəl\
PHYSICS. The law of hydrodynamics that states, in part, that when a liquid or gas flows through a tube or over a surface, the pressure is reduced at a right angle to the line of motion. The principle is illustrated by experiments showing that when a liquid or gas flows around an obstacle or passes through a constriction so that the speed of flow is increased, the pressure of the fluid against the wall is reduced.



TOMATOES

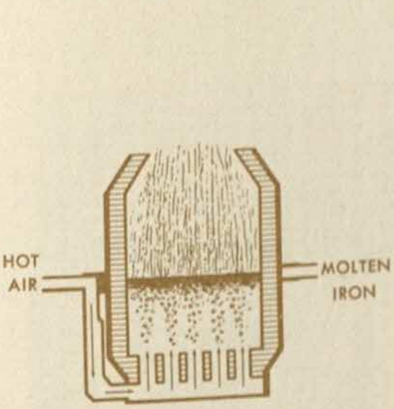
BERNOULLI'S PRINCIPLE, *when applied to flowing air, explains the principal source of lifting force by which a plane rises from the ground.*

berry \'ber-ē\ *n.*
BOTANY. A small or simple fruit composed of fleshy tissue.

Botanists classify the tomato as a BERRY.

Bessemer converter \'bes-ə-mər kən-'vərt-ər\
ENGINEERING. A large, pear-shaped metal container, used in the production of steel, in which a blast of air is forced through molten iron to remove carbon, silicon, phosphorus and other impurities.

Although open-hearth furnaces are more widely used, the BESSEMER CONVERTER *is still utilized by many steel mills.*



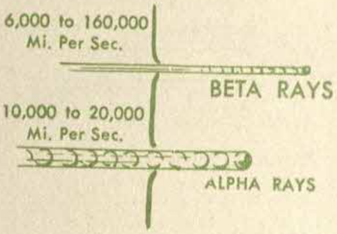
BESSEMER CONVERTER

beta particles \'bāt-ə 'pärt-i-kəlz\
PHYSICS. Electrons moving with velocities approaching 99 percent of the velocity of light. Beta particles are given off by atomic nuclei in their radioactive disintegration.

The direction of moving BETA PARTICLES *is changed as they pass through a magnetic field.*

beta rays \'bāt-ə 'rāz\
PHYSICS. A stream of electrons, or negatively-charged particles called beta particles, emitted in the decay of radioactive substances; one of the three rays—alpha, beta, gamma—given off by radioactive substances.

BETA RAYS *are more penetrating than alpha rays.*



betatron \'bāt-ə-ˌträn\ *n.*
PHYSICS. A device that accelerates electrons to very high velocities so they may be used to bombard the nucleus of an atom.

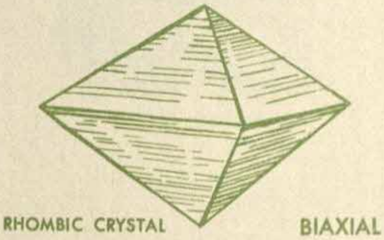
In a BETATRON, *the electrons are accelerated by a rapidly-changing magnetic field.*

biaxial \(')bī-'ak-sē-əl\ *adj.*
PHYSICS. Having two optic axes, or directions, in which no double refraction occurs.

Some crystals are BIAXIAL.

bicarbonate \(')bī-'kär-bə-ˌnāt\ *n.*
CHEMISTRY. A salt of carbonic acid, H_2CO_3, one hydrogen atom of which has been replaced by a metal; for example, $NaHCO_3$.

Baking soda is a common household BICARBONATE.

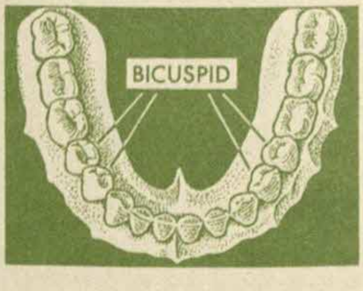


bicuspid \(')bī-'kəs-pəd\ *n.*
ANATOMY. In man, any of eight teeth having two points and located in pairs between the canines and molars on each side of the jaws; also, a valve located between the left auricle and left ventricle of the heart.

A BICUSPID *is also called a premolar.*

biennial \(')bī-'en-ē-əl\ *n.*
BOTANY. A plant completing its life cycle in two years. It produces leaves and roots the first year, and bears flowers, fruit and seed in the second.

The parsnip is a BIENNIAL.



bifocal \(')bī-'fō-kəl\ *adj.*
MEDICINE. Pertaining to a spectacle lens having two portions, one that corrects for near vision and the other that corrects for distant vision.

Young people usually do not need BIFOCAL *lenses.*

bilateral symmetry \(')bī-'lat-ə-rəl 'sim-ə-trē\
BIOLOGY. Having the right and left sides equal or identical, so

that one side appears to be a reflection of the other, as the right and left halves of the human body.

BILATERAL SYMMETRY *is characteristic not only of the external features of many common animals, but also of their internal organs.*

BILATERAL SYMMETRY

bile \'bī(ə)l\ *n.*

PHYSIOLOGY and ZOOLOGY. A bitter yellow or greenish fluid that is secreted by the liver and aids digestion.

BILE *is stored in the gall bladder.*

bile duct \'bī(ə)l 'dəkt\

PHYSIOLOGY and ZOOLOGY. Any duct of the liver by which bile is carried to the gall bladder or to the duodenum.

One important BILE DUCT, *the common bile duct, opens into the duodenum.*

billion \'bil-yən\ *n.*

MATHEMATICS. A word that represents a thousand millions in the United States and Canada but a million millions in Great Britain.

In the United States, the numeral written with a 1 followed by nine zeros, 1,000,000,000, is read "one BILLION."

bimodal curve \(')bī-'mōd-ᵊl 'kərv\

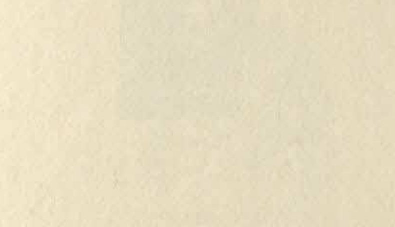
MATHEMATICS. A curve with two modes, or peaks, representing the two values, in a distribution of values, that occur with the highest frequency.

A BIMODAL CURVE *differs from a normal curve in that it has two modes instead of one.*

binary \'bī-nə-rē\ *adj.*

1. MATHEMATICS. Based upon two. 2. Consisting of two things or parts; using or combining two objects or elements; arranged by twos.

Addition is a BINARY *operation that gives us a rule for combining two numbers to obtain a single number called the sum.*



BIMODAL CURVE

binary coded decimal \'bī-nə-rē 'kōd-əd 'des-ə-məl\

ENGINEERING and MATHEMATICS. Referring to a method of representing decimals in the memory of a digital computer, in which a binary number stands for each digit in the decimal; *abbr.* BCD.

In the BINARY CODED DECIMAL *system, all numbers, letters and special symbols are represented by seven different binary combinations.*

binary compound \'bī-nə-rē 'käm-ˌpau̇nd\
CHEMISTRY. A compound consisting of only two elements.

The chemical name of a BINARY COMPOUND *usually ends in the suffix -ide, as in sodium chloride.*

binary digit \'bī-nə-rē 'dij-ət\
MATHEMATICS and ENGINEERING. The basic information symbol in the binary notation system used by digital computers, either 1 or 0; *abbr.* BIT.

In the electronic circuit of a digital computer, a BINARY DIGIT *is represented by either a closed or an open circuit.*

BINARY FISSION

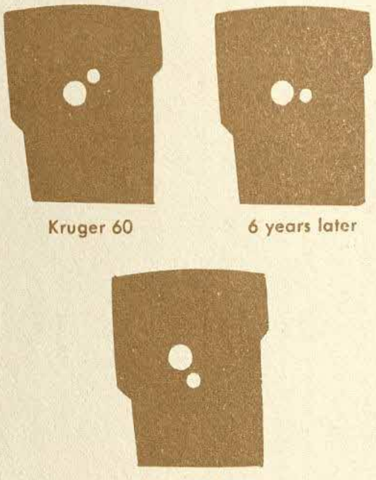
binary fission \'bī-nə-rē 'fish-ən\
BIOLOGY. The division of a cell into two separate and similar parts.

Protozoa can reproduce by BINARY FISSION.

binary notation \'bī-nə-rē nō-'tā-shən\
MATHEMATICS and ENGINEERING. The system of coding data for a digital computer. The system uses various combinations of two symbols, 0 and 1, to represent the desired numbers.

In BINARY NOTATION, *the symbol 1 indicates the absence of the power of 2 in the number represented, while the symbol 0 indicates its presence.*

BINARY STARS


Kruger 60

6 years later

12 years later

binary stars \'bī-nə-rē 'stärz\
ASTRONOMY. Two stars that revolve around a common center of gravity.

BINARY STARS *are also called double stars.*

binary system of numeration \'bī-nə-rē 'sis-təm əv ˌn(y)ü-mə-'rā-shən\
MATHEMATICS. A system in which only two symbols, 0 and 1, are used to represent numbers, and in which the positional value of a digit is the product of the digit and a power of 2, the power of 2 always being one less than the position of the digit from right to left in the numeral. Thus, 1101 in the binary system is equal to $1\cdot2^3 + 1\cdot2^2 + 0\cdot2^1 + 1\cdot2^0 = 8 + 4 + 0 + 1 = 13$.

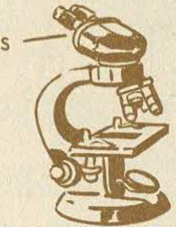
The numbers represented by the numerals 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9 in the decimal system of numeration are represented by the respective numerals 0, 1, 10, 11, 100, 101, 110, 111, 1000 and 1001 in the BINARY SYSTEM OF NUMERATION.

BINAURAL

binaural \(')bī-'nȯr-əl\ *adj.*
1. ANATOMY and ZOOLOGY. Having the use of two ears. 2. ENGINEERING. Referring to a method of sound reproduction in which

two microphones, in the relative positions of human ears, relay signals to separate receivers that together produce a sound with nearly the same dimension as the original; see *stereophonic.*

BINAURAL *hearing makes it possible to detect the direction from which a sound comes.*



BINOCULAR MICROSCOPE

binding energy \'bīn-diŋ 'en-ər-jē\
PHYSICS. The quantity of energy required to remove a particle from a system, such as a proton from the atomic number.

The BINDING ENERGY *of an electron is equal to its ionization potential.*

binocular microscope \bə-'näk-yə-lər 'mī-krə-ˌskōp\
A microscope that allows for use of both eyes simultaneously.

A very small object is viewed through a BINOCULAR MICROSCOPE, *just as a distant object is viewed through field glasses.*

binocular vision \bə-'näk-yə-lər 'vizh-ən\
ANATOMY and ZOOLOGY. Vision involving two eyes, in which slightly different images form on each retina because each eye sees an object from a slightly different angle.

Man's BINOCULAR VISION *allows him to view the world as having a third dimension, solidity or depth.*

binomial \bī-'nō-mē-əl\ *n.*
MATHEMATICS. An algebraic expression that is the sum or difference of two terms, such as a + b or a − b.

In an algebraic equation, a BINOMIAL *frequently appears in parentheses.*

BINOCULAR VISION

binomial nomenclature \bī-'nō-me-əl 'nō-mən-ˌklā-chər\
BIOLOGY. A system for designating all species of plants and animals by two names: according to their genus and according to their species.

When using the system of BINOMIAL NOMENCLATURE, *the name for man is* HOMO SAPIENS.

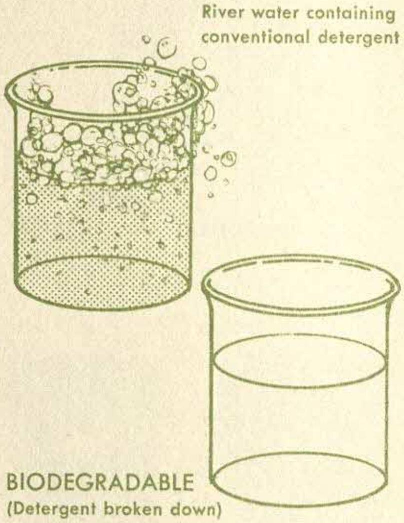
biochemistry \ˌbī-ō-'kem-ə-strē\ *n.*
BIOLOGY and CHEMISTRY. A branch of chemistry dealing with the composition of living plants and animals and their life processes.

The science of BIOCHEMISTRY *developed as a result of applications of the principles of chemistry in biology.*

biodegradable \ˌbī-(ˌ)ō-di-'grād-ə-bəl\ *adj.*

BIOLOGY and CHEMISTRY. A characteristic of a substance that can be broken down by bacterial action.

BIODEGRADABLE *detergents are now being sold for household use.*


River water containing conventional detergent
BIODEGRADABLE
(Detergent broken down)

biogenesis \ˌbī-ō-'jen-ə-səs\ *n.*

BIOLOGY. The theory that living organisms are produced only by other living organisms.

The theory of BIOGENESIS *is directly opposite to the theory of spontaneous generation.*

biological control \ˌbī-ə-'laj-i-kəl kən-'trōl\

BIOLOGY. The destruction or reduction of undesirable organisms, either plant or animal, by upsetting the balance of their environment; for example, by introducing organisms hostile to them.

Man uses BIOLOGICAL CONTROL *to reduce the numbers of insect pests.*

biologist \bī-'äl-ə-jəst\ *n.*

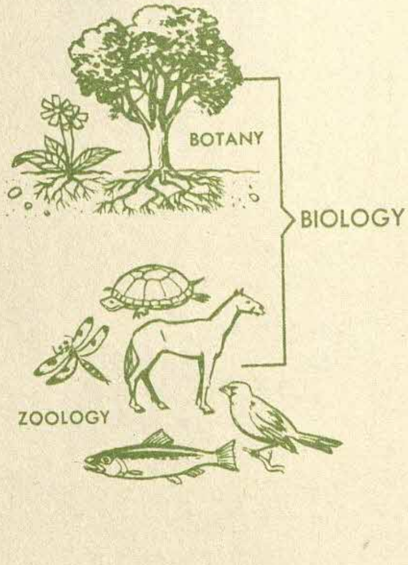
BIOLOGY. A scientist who studies all types of living things, including their physical structure and function, their natural habitat, their development from prehistoric times and all other matters related to their life activities.

A BIOLOGIST *must have a background in several fields of science.*

biology \bī-'äl-ə-jē\ *n.*

The science of living things.

Some major branches of BIOLOGY *are botany, zoology and bacteriology.*



biome \'bī-ˌōm\ *n.*

BIOLOGY. The community of all the plants and animals in a given region; a mature or climax community of plants and animals.

The different animal and plant members of a BIOME *are dependent upon each other.*

biometrics \ˌbī-ō-'me-triks\ *n.*

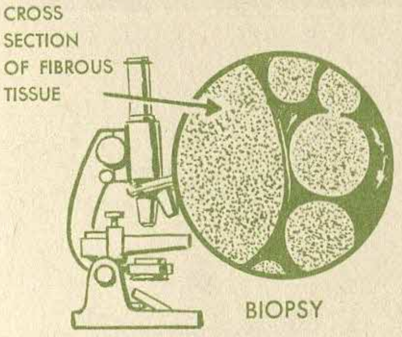
BIOLOGY. The use of statistical or mathematical calculation in biology, as in determining probable length of human life.

BIOMETRICS *is a useful study in the field of anthropology.*

bionics \bī-'än-iks\ *n.*

BIOLOGY and ENGINEERING. A science that endeavors to duplicate the unusual sensing abilities of living organisms and adapt them to man's use through electronics. The word was coined by Air Force scientist Major J. E. Steele in 1960.

The bat is one of the animals that has been the subject of research in BIONICS.



BIOPSY

biophysics \ˌbī-ō-'fiz-iks\ *n.*
BIOLOGY and PHYSICS. The study of biological structures and processes with reference to the principles and phenomena of physics.

The effects of radioactivity on living things are studied as a part of BIOPHYSICS.

biopsy \'bī-ˌäp-sē\ *n.*
MEDICINE. The removal and examination, usually microscopic, of a piece of living tissue from a body.

A doctor or dentist uses a BIOPSY *as a diagnostic aid.*

BIPED

biosphere \'bi-ə-ˌsfi(ə)r\ *n.*
BIOLOGY. The areas of the earth, and the earth's atmosphere, that are inhabited by plant and animal life.

The BIOSPHERE *includes most of the earth's surface and lower atmosphere.*

biota \bī-'ōt-ə\ *n.*
BIOLOGY. The plant and animal life of a particular region or period.

BIOTA *is a term used collectively for flora and fauna.*

biotic \bī-'ät-ik\ *adj.*
BIOLOGY. Relating or pertaining to life or living things.

Darwin's theory of evolution is a statement of BIOTIC *principles.*

biped \'bī-ˌped\ *n.*
ZOOLOGY. A two-footed creature, such as a bird.

Man is a BIPED.

BIPLANE

biplane \'bī-ˌplān\ *n.*
AERONAUTICS. An airplane having two wings, with one above the other.

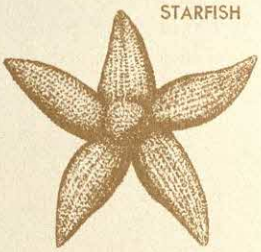
The Wright brothers made their historic flight in a BIPLANE.

bipolar \(')bī-'pō-lər\ *adj.*
1. PHYSICS. Having two poles, positive and negative, as a magnet. 2. EARTH SCIENCE. Having two poles, north and south, as the earth.

A compass needle always points north because it is a BIPOLAR *magnet.*

bipropellant \ˌbī-prə-'pel-ənt\ *n.*
ASTRONAUTICS. A rocket propellant having two unmixed chemicals that are fed to the combustion chamber separately.

One chemical in a BIPROPELLANT *is fuel, and the other is an oxidant.*



BIRADIAL SYMMETRY

biradial symmetry \(')bī-'rād-ē-əl 'sim-ə-trē\
BIOLOGY. A structure in which similar parts have both radial and bilateral symmetry.

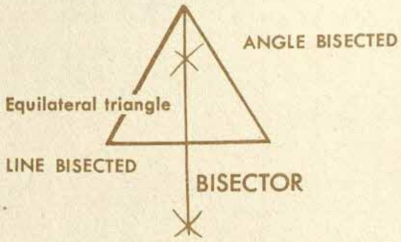
Starfish have BIRADIAL SYMMETRY.

bisect \'bī-ˌsekt\ *v.*
MATHEMATICS. To divide into two equal parts.

A pair of compasses and a straightedge may be used to BISECT *an angle.*

bisector \'bī-ˌsek-tər\ *n.*
MATHEMATICS. A straight line that bisects another line segment, angle or figure.

The perpendicular BISECTOR *of a side of an equilateral triangle bisects the angle opposite that side.*



bisexual reproduction \(')bī-'seksh-(ə)wəl ˌrē-prə-'dək-shən\
BIOLOGY. The generation of offspring through the process of union between male and female reproductive cells; contrasted to asexual reproduction.

All mammals reproduce by the process of BISEXUAL REPRODUCTION.

BIT
An abbreviation for binary digit. See *binary digit.*

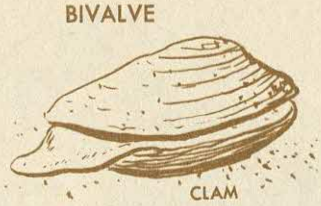
bituminous coal \bə-'t(y)ü-mə-nəs 'kōl\
EARTH SCIENCE. Soft coal; coal that is high in carbonaceous and volatile matter.

When the volatile materials are removed from BITUMINOUS COAL *by extreme heating in the absence of air, the coal becomes coke.*

bivalent \(')bī-'vā-lənt\ *adj.*

CHEMISTRY. Combining with two atoms of hydrogen or another univalent element; having a valence of two.

Zinc is BIVALENT.



bivalve \'bī-ˌvalv\ *n.*

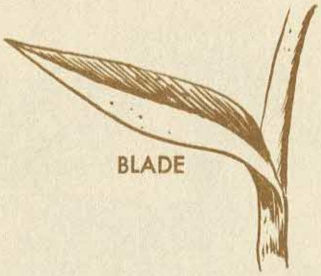
1. ZOOLOGY. Any mollusk or brachiopod having two shells that are hinged together. 2. BOTANY. Having two valves, as a seed-case or capsule.

A clam, an oyster or a mussel is an example of a BIVALVE.

blackbody \'blak-'bäd-ē\ *n.*

PHYSICS. A theoretical, completely black object or surface that would absorb all radiant energy striking it.

A BLACKBODY *is an ideal that scientists have not achieved in reality.*



blackout \'blak-au̇t\ *n.*

PHYSIOLOGY. A temporary vision loss followed by unconsciousness, caused by inadequate blood circulation in the brain. It is frequently brought on by a sudden increase in gravitational force on the body, as in the rapid recovery of an aircraft from a fast, steep dive, or in rapid acceleration of a rocket leaving the earth.

Pilots of fast, highly maneuverable aircraft are protected from BLACKOUT *by pressurized suits, which prevent the collection of blood in the lower parts of the body.*

bladder \'blad-ər\ *n.*

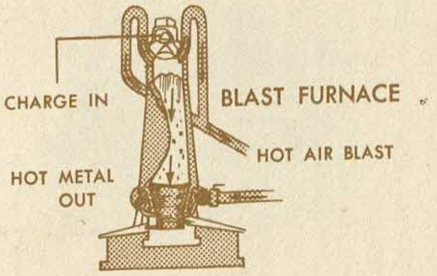
ANATOMY and ZOOLOGY. A sac of membranous tissue in the bodies of many animals that receives and stores liquids or gases that are later expelled.

The air BLADDER *of a fish makes a change in its buoyancy possible.*

blade \'blād\ *n.*

BOTANY. The flat, expanded part of a leaf or similar structure; also called the lamina.

Photosynthesis occurs chiefly in the BLADE *of a leaf.*



blast furnace \'blast 'fər-nəs\

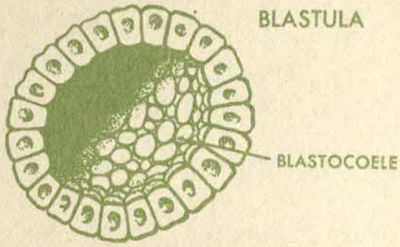
CHEMISTRY. A towerlike furnace that uses a blast of intensely-heated air to reduce the ores of metals and to remove impurities from the ore.

Combustion is forced in a BLAST FURNACE *by a current of air under pressure.*

blastula \\'blas-chə-lə\\ *n.*

ZOOLOGY. An early stage of embryonic development in many animals.

The cells of the BLASTULA *are usually arranged in a sphere, with walls of a single layer completely surrounding a closed cavity called the blastocoele.*



bleach \\'blēch\\ *n.*

CHEMISTRY. A chemical used to remove unwanted coloring matter or stain from fibers or other materials.

Chloride of lime is used as a BLEACH.

blight \\'blīt\\ *n.*

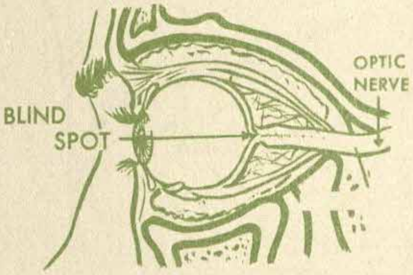
BOTANY. Any atmospheric or soil condition, or insect or parasite, that injures or kills plants or that checks the growth of plants without causing them to decay; also, the plant disease itself.

The woolly apple aphid sometimes causes an apple tree BLIGHT.

blind spot \\'blīnd 'spät\\

ANATOMY and PHYSIOLOGY. A small, light-insensitive area of the retina of the eye where the optic nerve enters.

The BLIND SPOT, *also called the optic disc, is located only about three mm. from the point of clearest vision.*



blink microscope \\'bliŋk 'mī-krə-ˌskōp\\

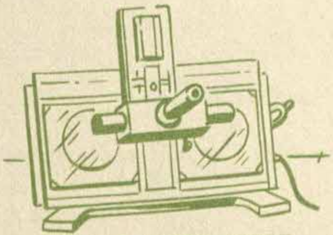
ASTRONOMY. A magnifying instrument that compares two photographs of a celestial region by showing them alternately in rapid succession.

A BLINK MICROSCOPE *can detect unusual star movements or changes in brightness that would otherwise go unnoticed.*

block fault \\'bläk 'fȯlt\\

EARTH SCIENCE. Faults, or cracks, in a mass or rock, occurring in the shape of blocks.

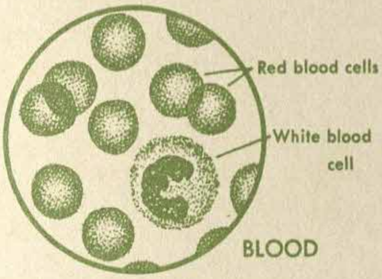
BLOCK FAULT *is usually found in soft rock.*



blood \\'bləd\\ *n.*

ANATOMY and ZOOLOGY. A reddish fluid, circulating in the heart, arteries and veins, that carries food and oxygen to all parts of the body and carries away the waste products of metabolism.

BLOOD *contains red corpuscles, white corpuscles and plasma.*



blood count \'bləd 'kau̇nt\

MEDICINE. A count of the number of red and white corpuscles in a definite volume of blood.

A BLOOD COUNT *is often made in diagnosing diseases and infections.*

blood group \'bləd 'grüp\

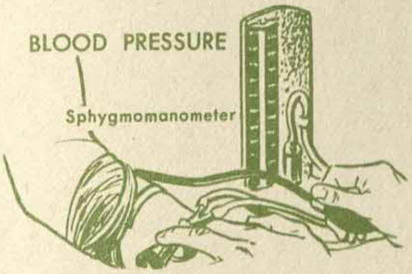
MEDICINE and PHYSIOLOGY. One of the classes by which the blood of human beings may be identified on the basis of certain chemical characteristics. The common types are O, A, B and AB.

A universal donor is in the type O positive BLOOD GROUP.

blood plasma \'bləd 'plaz-mə\

MEDICINE and PHYSIOLOGY. The fluid part of the blood in which the red and white corpuscles are suspended.

BLOOD PLASMA *is used in some transfusions.*



blood pressure \'bləd 'presh-ər\

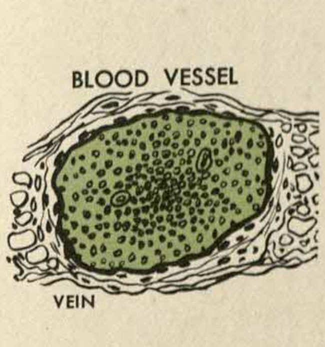
MEDICINE and PHYSIOLOGY. The pressure of the blood against the inner walls of the blood vessels, particularly the arteries, varying in amount with such factors as age, physical condition or emotional tension.

BLOOD PRESSURE *normally increases with age.*

blood sugar \'bləd 'shu̇g-ər\

MEDICINE and PHYSIOLOGY. The sugar, or glucose, in the blood; also, the amount of sugar in the blood.

In an emergency, the body's BLOOD SUGAR *is increased.*



blood vessel \'bləd 'ves-əl\

ANATOMY and ZOOLOGY. Any canal or tube in an animal through which blood circulates.

A BLOOD VESSEL *is an artery, a vein or a capillary.*

blowout \'blō-,au̇t\ *n.*

EARTH SCIENCE. A depression or hollow caused by wind in areas of sandy or loose soil.

A BLOWOUT *may range from a few feet to several miles in diameter.*